MSc Thesis in Complex Systems Engineering & Management

UNTANGLING THE WILD WEST

Exploring the applicability of blockchain-based applications to prevent double counting in the voluntary carbon by developing a multi-level governance blockchain evaluation framework

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2022

TU Delft

UNTANGLING THE WILD WEST

A thesis submitted to the Delft University of Technology in partial fulfillment of the requirements for the degree of

Master of Science in Complex Systems Engineering & Management

by

Suzanne Post

August 2022

Suzanne Post: *Untangling the Wild West* (2022)

ISBN 999–99–9999–999–9

The work in this thesis was made in the:

EY Finance Technology Tribe, and
Department of Information & communication
Faculty of Technology, Policy& Management
Delft University of Technology

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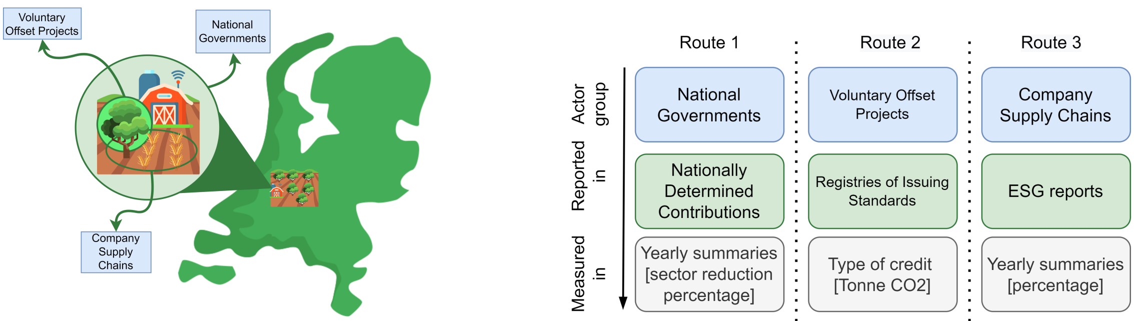
EXECUTIVE SUMMARY

The modern world is under great pressure to fight climate change and limit global temperature rises to a sustainable level. As part of new mitigation strategies, the Voluntary Carbon Market (VCM) emerged after the compliance markets materialized. Via the voluntary carbon market companies can offset their carbon emissions and demonstrate their commitment to sustainability to the public. The captured carbon is transformed into 'carbon credits' representing one tonne of Greenhouse gas (GHG) emissions captured or reduced.

Due to the rapid emerging of the VCM and the complex nature of carbon offsetting, standardization and adequate administrative governance are lagging. Hence, the voluntary carbon market was often referred to as the 'Wild West' over the past years. One of the leading quality and integrity concerns is the potential double counting of credits, possible due to different schemes that exist in the global carbon market. In a nutshell, the voluntary carbon market is based on voluntary carbon offset projects, compliance schemes require governments to report its national mitigation activities in Nationally Determined Contributions (NDC)s, and the private sector needs to report on their environment, governance and sustainability responsibilities. Double counting occurs among these three activities when captured carbon is allocated to more than one actor. In Figure 0.1, (a) depicts the double counting of the carbon removal between a voluntary offset project, a company's supply chain, and a country's national mitigation activities. (b) shows a schematic version of the different actors, with their corresponding reporting formats and measurement units. At present, despite many administrative initiatives to streamline the market, the possibility of double counting is still unresolved.



(a) Claiming of carbon removal by actors

(b) Reporting responsibilities per actor

Figure 0.1: A schematic depiction of the possibility to double count

The intangible nature of the carbon credit, based upon large amounts of dispersed data, complicates the formulation of a singular definition and complicates the unification of accounting practices between project developers, standard registries, verifiers, and consumers. There is a need for improved information systems to share data to increase transparency and support data accuracy and reliability. Innovative technology like blockchain could potentially fill this need and solve the aforementioned problems, including double counting. Blockchain technology can offer the required transparency, traceability, accountability, security, and immutability. However, designing adequate blockchain-based systems for a complex environment like the VCM is challenging. It requires tailoring to the fragmented nature of the market, the intricate composition of the traded asset, and the diverging stakeholder interests. Accordingly, there is a need to look at blockchain-based systems for the VCM through a socio-technical systems view.

This thesis project examines the research domain of blockchain-based platform solutions by investigating the benefits and limitations of facilitating the minting[1] and subsequently the trading of carbon credits. For this reason a framework that evaluates blockchain-based platforms concerning the influences of socio-, governmental- and technical requirements on blockchain design choices is developed. The so called 'Multi-Level Governance Blockchain Evaluation framework' (MLGBE) framework identifies stakeholder dynamics and requirements which need to be understood to design apt blockchain solutions for the VCM. It must also be understood from reasoning backwards from technology limitations how these affect multi-level governance and stakeholder formations. The research question for this thesis project is formulated concomitant to the research objective:

What framework can be developed to evaluate the benefits and limitations of blockchain-based platforms to prevent double counting in the voluntary carbon market?

A single case study approach is followed to answer the main research question, in which the study of a specific case is used to obtain a larger understanding of an issue or phenomenon. Additionally, a single case study can represent a significant contribution to knowledge and theory building by confirming, challenging or extending theory, in which the framework is the theory to be developed. Case studies often utilize theoretical frameworks to focus the research. As voluntary carbon offsetting is an undoubtedly new and complex market, a theoretical framework was necessary to situate the researcher in a scholarly conversation, determine what data needed to be collected and facilitate data interpretation. Academic literature on blockchain evaluation frameworks was sought to guide the thesis. Only, the framework of van Engelenburg et al. [2020] adopted a socio-technical systems view on blockchain-based platforms, to assess the alignment between stakeholders interest and blockchain design choices. Therefore, it was used throughout the research.

The case of Acorn Rabobank was selected as an opportunity of unusual research access presented itself. Acorn is both a project developer of carbon credits and the enabler of its own digital marketplace. Acorn establishes agroforestry offset projects in collaboration with smallholder farmers, in which the carbon sequestered by the newly planted trees is transformed into a credit. Acorn intends to increase market quality by being transparent in their methodologies, processes and governance structures.

The research activities consisted of selecting and defining the case, data collection, data interpretation, and theory building. First, the knowledge base for the research created by performing extensive desk research and theoretical sampling, which facilitated the problem demarcation of double counting experienced by the global carbon market. Three forms of double counting were established, as depicted in Figure 0.1. To further enrich the knowledge base the stakeholder dimension was mapped based on secondary sources and empirical knowledge gained through preliminary interviews. Several mapping techniques (i.e.formal chart, value model analysis, conceptual modelling, and business process modelling) were employed to map the interrelations between the market mechanisms and double counting. Next, the data for the case analysis was collected from multiple data sources, through additional desk research and semi-structured, open-ended interviews with experts of Acorn and blockchain experts. The data analysis employed the computer-assisted qualitative data analysis software Atlas.ti. Large amounts of data were coded and categorized iteratively to identify patterns and emergent theories from the data. The framework was also developed iteratively, including two feedback and validation rounds with one scholar and field expert.

Te MLGBE framework allows carbon market actors to evaluate and, if applicable, reason about the various available blockchain based-infrastructures as tokenizing carbon credits and the digitized trading of these credits.

1 Minting is the process of generating new tokens by authenticating data, creating new blocks and recording the information onto the blockchain.

By doing so, they can identify the stakeholder dynamics with all policies, interrelated treaties and community plans in place, to develop or evaluate sustainable blockchain-based platforms tailored to the market to prevent double counting.

The thesis provided several scientific and practical contributions. Scientifically, new theory on multi-level governance information sharing by making use of blockchain applications was built trough the development of the MLGBE framework. The framework draws on two schools of theory, namely multi-level governance and business & governance information sharing based on innovative technologies, captured in established frameworks [Shigaeva et al., 2013; van Engelenburg et al., 2020]. By integrating these two schools to the particularities of asset tokenization in blockchain applications, a new approach to evaluate blockchain designs is presented. The framework enriches the limited base of blockchain evaluation frameworks in literature. Secondly, the research delineates the issue of double counting in the voluntary carbon market, synthesising the interrelations between the voluntary carbon market and compliance market and drawing attention to empirical carbon offsetting issues. Such an overview was missing in the extant literature. Lastly, the research corroborates earlier findings in the logistics domain of the importance of reliability of data elements of blockchain-based applications used for audit-trails. On a practical level, the research presents a new approach to reason about blockchain designs, thereby aiding project developers, businesses, NGOs, standardisation bodies and government agencies. To help these actors to determine what requirements exist to design suitable blockchain systems or to decide against the adoption of blockchain-based systems in a grounded manner.

Concerning double counting further research is recommended on the potential of blockchain solutions to link schemes together to facilitate a global carbon market, how these link to the eventual implementation of Article 6, and the potential nesting within countries' NDCs. For the MLGBE framework, future research should look into the interaction between the standardization/fragmentation dependent on policy layers and the different rights in the governance requirements.

ACKNOWLEDGEMENTS

This research project signs the end of my studies. My educational experience equipped me with the skill to delineate any problem, identify constraints and requirements to design technical interventions. This project provided me with the opportunity challenge myself by exploring two previously unfamiliar domains, namely blockchain technology and the voluntary carbon market. Despite a rocky start, it has been a rewarding experience from which I have learned a lot.

I would like to express my gratitude towards everyone that played a significant role in my research project. Firstly, I would like to deeply thank my external supervisor, Dr. Boriana Rukanova, for her supervision the past couple of months and our joined journey to understanding the voluntary carbon market. Our lengthy discussions always provided me with new insights and thoughts to structure and improve my research. Without her critical view and expertise of business and governance information sharing and supportive guidance, this research in such a novel and intriguing research domain would not have materialized.

Equally important was the contribution of Ir Emma van de Ven. Because of her generosity and willingness to provide access to Acorn, I was able to study the applicability of blockchain technology to prevent double counting. Her extensive contributions to this research project, in both time and access have elevated the research to a higher-level. Our insightful and enjoyable discussions sparked my interest in delving deeper into the domain and advanced my skills. Furthermore, I would like to extend my thanks to Prof.dr. Marijn Janssen for substituting as chair in the middle of my research process, making the time to provide insightful feedback despite his busy schedule. Our meetings provided me with food for thought to keep my research comprehensible and stay on course. Moreover, I want to thank Dr. Jaco Quist for contributing to my efforts from an sustainable innovation and transitions perspective and for sharpening my research by his remarks. Last but not least, I would like to express my gratitude with Ir. Rafael Costa, whom introduced me to the domain of carbon markets and helped me to kick-off my research. Without his supervision I would not have found such a novel and interesting research subject. I have thoroughly enjoyed your thoughtful supervision and the opportunity you provided for me to reach out anytime. My acknowledgements also go to the experts who shared their knowledge with me.

On another note, I would like to express my gratitude towards my friends and family for supporting me throughout the research process. Special thanks to Niels van Kouwen, Kees Keulemans and Anniek Bertels, our coffee breaks, short walks and shared graduate journey with and have made my research process all the more enjoyable.

Enjoy reading,

Suzanne Post

Delft, August 2022

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ACRONYMS

1 INTRODUCTION

This thesis research was conducted at Delft University of Technology, under the supervision of Ernst & Young - Finance Technology in collaboration with Rabobank Acorn (from hereon referred to as Acorn). The thesis aspires to create some clarity in the chaos of voluntary carbon offsetting, by researching the issue of double counting and exploring the benefits and limitations of blockchain to address this issue. This is done via the in-depth study of a project developer (Acorn) in the VCM. Basically, a single market actor is used to better understand the wider context. The findings from the case will help to clarify current double counting issues, delineate the stakeholder dynamics and identify considerations and requirements to prevent double counting in the VCM.

This chapter functions as the skeleton of the research project. It sets the foundation for the research by introducing the main research problem in Section 1.1. Consecutively, the key concepts in the research, namely *the voluntary carbon market, double counting, blockchain and distributed ledger technology and carbon accounting*, are defined to avoid any ambiguities. This is followed by a state of the art literature review in Section 1.2 to search the extant literature on double counting in the voluntary carbon market and on current blockchain applications in the voluntary carbon market. The literature review identifies the knowledge gaps in extant literature in Section 1.3. The knowledge gaps assist in defining the main research question and corresponding research objective. Together they capture the thesis its contributions towards both the academic field ans society in general.

The first knowledge gap identified, was the lack of understanding of what double counting is, in what forms it can occur empirically and how to capture this in a comprehensive overview for the VCM. The second knowledge gap identified was the scarce research on the applicability of blockchain technology to the VCM and scarce research on blockchain solutions for the VCM. The third and last knowledge gap is the scarce amount of frameworks that allow for the evaluation of blockchain solutions. Even less common are frameworks that allow for the analyses of the interrelation between stakeholder dynamics and specific blockchain solutions. No framework to evaluate blockchain solutions in the context of the VCM exists to the knowledge of the thesis. Combined these knowledge gaps led to the formulation of the main research question in Section 1.4: *What framework can be developed to evaluate the benefits and limitations of blockchain-based platforms to prevent double counting in the voluntary carbon market?*

The chapter is concluded with the research sub questions in Section 1.6, which are delineated from the main research question. These sub-questions allow for the research to be divided into more comprehensible components. Additionally, Table 1.1 provides an overview of the methods used to answer each sub-question as well as related deliverables.

1.1 PROBLEM INTRODUCTION

Climate change is one of the main challenged faced by the world today [Fekete et al., 2021]. Current projections predict that average global temperature could rise by 3-6 degrees Celsius by 2100 without urgent action [Masson-Delmotte et al., 2018]. To limit the rise to 2 degrees Celsius, the world needs zero net greenhouse gas emissions by the end of the century [Masson-Delmotte et al., 2018]. From 2015 to 2040, an increase of 16% is predicted for energy-related CO2 emissions worldwide. Carbon dioxide made for 75% of the global greenhouse gas emissions in 2010 and will continue to rise at an average of 0.6% per year between 2015 and 2040 [Khaqqi et al., 2018; Masson-Delmotte et al., 2018]. Emissions would need to peak before 2030 to give any real chance of reaching net zero greenhouse gas emissions. Such dramatic emissions reductions can only be achieved by far-reaching national and international climate policies [Fekete et al., 2021; Masson-Delmotte et al., 2018; López-Vallejo, 2022].

Over the past two decades, there has been increased action by the global community to limit the damaging effects of climate change and greenhouse gas emissions [Andrić et al., 2019; Chowdhury et al., 2021; Fekete et al., 2021; Gallo et al., 2016; Franke et al., 2020; Interpol, 2013]. International concern about climate change led to the Kyoto Protocol in 1997 which contains legally binding emission targets for industrialized countries to be achieved during 2008-12 [Böhringer, 2003]. While the Kyoto Protocol requires signatory countries to meet their targets primarily through domestic measures, it also provides for a number of flexible mechanisms that allowed parties to offset their emissions by purchasing reductions made in other countries [Blum, 2020]. Since then, carbon offsetting has become an increasingly popular means of taking action. Done through the purchasing of "units", each unit being equivalent to one tonne of CO2. Through the trading of these units to offset emissions of greenhouse gases, a new commodity has been created in the form of emission reductions or removals [Schneider et al., 2018]. Since carbon dioxide (CO2) is the principal greenhouse gas, this market is widely referred to as the *'carbon market'*, with the units traded commonly referred to as *'carbon credits'* [Interpol, 2013].

Carbon offset markets exist both under compliance schemes and as voluntary programs. Compliance markets are created and regulated by mandatory regional, national, and international carbon reduction regimes, such as the Paris Agreement and the European Union's Emissions Trading Scheme [Broekhoff et al., 2019a; Schneider et al., 2014]. Voluntary offset markets function outside of the compliance markets and enable companies and individuals to purchase carbon offsets on a voluntary basis [Broekhoff et al., 2019b]. Carbon offsetting has received noteworthy attention by policymakers, scholars, Non-Governmental Organization (NGO)s and businesses as an opportunity to increase climate change action [Adams et al., 2021; Lang et al., 2019; López-Vallejo, 2022; Rabobank, 2021; Schneider et al., 2014]. However, both the compliance and voluntary market have been thoroughly criticized on the quality of carbon offset projects. The voluntary offset market in particular has been criticized for its lack of transparency, quality assurance and third-party standards, negatively impacting consumer trust in the market [Blum, 2020; Lang et al., 2019; López-Vallejo, 2022; Schneider et al., 2014, 2020].

One of the leading quality and integrity concerns is the double counting of credits [Cörvers et al., 2022; López-Vallejo, 2022; Sato and Nojiri, 2019; Schneider et al., 2014] – when emission reductions or removals are counted more than once [Blum, 2020]. Double counting is the result of multiple unconnected registries and corresponding lack of uniform methodologies for generating, monitoring and reporting carbon credits. These carbon offset registries keep track of offsets and are vital in minimizing the risk of double counting. Registries also clarify ownership of offsets. There is no one single registry for the whole of the voluntary market. Registries for the voluntary market have been developed by governments, non-profits, and the private sector. Some of the registries are tied to certain standards whereas others function independently, the differences between the current standards have made efforts to coordinate them so far unsuccessful [Blum, 2020].

According to Adams et al. [2021], novel approaches and digital infrastructures to share information are required to reduce the lack of transparency, traceability and immutability as well as increase accounting standards. Among the several digital infrastructures that can be found in the information systems literature, blockchain has gained significant attention for its potential to structure the carbon market by plenty of researchers [Franke et al., 2020; Fu et al., 2018; Khaqqi et al., 2018; Hartmann and Thomas, 2020; Li et al., 2021; López-Vallejo, 2022; Mandaroux et al., 2021; Schneider et al., 2014; Wang et al., 2020]

Blockchain is defined as *"an emerging technology enabling a decentralized repository of data that allows secure transactions between untrusted parties with an algorithmic-based consensus"* [Mandaroux et al., 2021]. Blockchain as an information-sharing system could be part of the solution to tackle the issue of double counting due its technical characteristics [van Engelenburg et al., 2020; Rukanova et al., 2021b,a]. One of its technical characteristics is transparency, which leads to accountability [Ashley and Johnson, 2018; Francisco and Swanson, 2018; Zheng et al., 2017; Wang et al., 2020]. If the blockchain is equated to a ledger book, a block is equivalent to a page in the book; in it a collection of events that happen in a certain timeframe are written [Khaqqi et al., 2018]. Over the interlinkage of the blocks, traceability and transparency are established. With all information accessible for scrutiny, participants are forced to conduct themselves in a responsible and accountable manner. This makes blockchains especially suitable as tracking systems [Agrawal et al., 2021; Francisco and Swanson, 2018; Franke et al., 2020]. Hence, these characteristics of blockchain—decentralized, transparent, immutable, and irrevocable—are favorable characteristics, that could help protect the system from double counting issues [Khaqqi et al., 2018; Wang et al., 2020].

This study extends the application of blockchain-based systems by exploring its opportunities for the VCM. By doing so, the transparency and quality of the VCM can be enhanced, however, an essential prerequisite for unleashing the full potential of shared data to serve society is the need for data reliability and quality. In other words, data recipients want assurance that the data has not been tampered with. This requirement can be satisfied by deploying blockchain-based systems.

Thus far, blockchains blockchains have been designed or deployed focused on the compliance market [Sipthorpe et al., 2022]. Nowadays, more initiatives are trying to enter the VCM IHS Markit [2022]; The World Bank [2019]. The fast growth of the VCM and the possibility for blockchain technology to radically disrupt the VCM incentivized the thesis to explore its suitability to prevent double counting. The research can profit greatly from studying blockchain solutions designed for the VCM. Specifically, the research can receive valuable insights from blockchain initiatives focused on providing end-to-end transparency in the supply chain of carbon credits. Such blockchain applications are likely to be used by NGOs, credit registries, supervisory bodies, and government agencies to track and validate mitigation claims. Simply put, the vcm actors can deploy them to trace a credit throughout its supply chain and verify whether it is minted and traded correctly.

1.2 INTRODUCING KEY CONCEPTS

To identify state of the art literature and define the knowledge gap of the problem domain introduced above, a literature review is conducted on the available literature on the carbon market and the inherent double counting, the possibilities for applying blockchain to improve carbon accounting, and conceptual frameworks that allow for the systematic evaluation of blockchain designs in order to draw grounded conclusions on the blockchain solution provided by Acorn. The literature search is guided by several core concepts, identified during the problem demarcation. To further scope the thesis, it is important to establish a mutual understanding of these core concepts early on. The concepts and their definitions are introduced in the following sections.

1.2.1 Search Method

To conduct the review four different search terms have been used to frame and identify the knowledge gap. First a search has been performed on "double counting" "carbon market" this resulted in a total of 8 papers, from which 6 articles were selected. Two papers were excluded due to the focus not being on carbon reductions or carbon markets itself. Next, a search was performed on blockchain "double counting", which reaped 3 results from which two articles were previously identified. Consecutively, the search for blockchain ("carbon market" OR ets) was performed to identify current applications with a total of 33 results. After reviewing the articles 9 articles were included. The search into evaluation frameworks reaped 29 results, from which only 5 articles were selected since they were the only frameworks evaluating or conceptualizing blockchain in a broader perspective. In the following paragraphs the results of the literature are discussed, which together lead to the knowledge gaps in Section 1.3.

1.2.2 Carbon Market Mechanisms

Firstly, the *VCM* enables companies and individuals to purchase carbon offsets on a voluntary basis with no intended use for compliance purposes. The VCM functions outside of the compliance markets and voluntary offset market credits, unless explicitly accepted into the compliance regime, are not allowed to fulfill compliance market demand [Broekhoff et al., 2019a].

Double counting is defined as the occurrence of two parties claiming the same carbon removal or emission reduction [Blum, 2020]. It is important to note that double counting can take on several forms, which will be researched more thoroughly later on. Fundamental to double counting is carbon accounting. The umbrella definition provided of *Carbon accounting* is given by Stechemesser and Guenther [2012], *"it comprises the recognition, the non-monetary and monetary evaluation and the monitoring of greenhouse gas emissions on all levels of the value chain and the recognition, evaluation and monitoring of the effects of these emissions on the carbon cycle of ecosystems."*

Monitoring, Verification and Certification ensure that offsets are "real, additional, and permanent." They include definitions and rules for the elements that are essential during the design and early implementation phase of a project. These include additionality and baseline methodologies, definitions about accepted project types and methodologies, validation of project activity etc [Kollmuss et al., 2008].

1.2.3 Blockchain and Distributed Ledger Technology

Blockchain and the Distributed Ledger Technology (DLT), is an emerging technology enabling a decentralized repository of data that allows secure transactions between untrusted parties with algorithmic-based consensus [Mandaroux et al., 2021]. Further, a distinction is made between a blockchain and a blockchain-based system.

Where a blockchain denotes a singular decentralized network between untrusted parties engaging in transactions, *blockchain-based systems* are viewed as complex socio-technical systems in which many stakeholders with divergent interests are involved [van Engelenburg et al., 2020].

1.2.4 Evaluation Frameworks

Blockchain design components and business outcomes differ from traditional technologies and business models due to the decentralized nature of the infrastructure that relies on peer-to-peer information exchange. Business value is collectively generated by nodes, and cooperation on intra- and inter-organizational levels is required to fully leverage the technology [Labazova, 2019]. For blockchains to be implemented in existing socio-technical systems, many factors of IT infrastructure, inter-organizational governance, and societal interactions should be considered simultaneously [Labazova, 2019; van Engelenburg et al., 2020]. Performing an analysis of a blockchain configuration without a suitable evaluation framework according to Labazova [2019] leads to *"misunderstandings of the core purposes of blockchains, mismatches between blockchain design components, failures in interoperability with existing IT solutions, and confusions regarding future visions of technology."*. Hence, an adequate evaluation in the case of Acorn is imperative, in which evaluation is seen as the systematic determination of a subject's merit, worth and significance, using criteria governed by a set of standards. Extant literature will be examined for a fitting framework to guide the research.

1.2.5 The Issue of Double Counting in Carbon Markets

Searching in the extant literature on carbon markets and blockchain, seven relevant articles are identified via Scopus. First, a quick summary of the included literature is provided after which the literature is categorized to provide concurrent themes.

López-Vallejo [2022] aimed to present an overview of offset programs worldwide, discuss the leading principal quality issues of non-additionality, overestimated supply and double counting and evaluate the upcoming Mexican Emission Trading System (ETS) market. They highlighted the existence of significant differences among offset programs. Within offset programs, quality assessment is fundamental to overcoming problems [López-Vallejo, 2022]. In their review, they too discussed that the Paris Agreement parties could not reach a consensus for designing a trust worthy global offset accounting system. The cases of CDM and JI prove that quality is necessary for legitimizing the use of market approaches to addressing climate change. They argue that double counting can only be prevented by transparency and a clear, current, and open database in the Mexican ETS.

Blum [2020] assesses the legitimacy of the carbon market and finds that carbon markets remain contested and require new ideas and concepts to construct legitimacy. She too emphasizes that the voluntary market is not regulated by an international administrative body, making voluntary standards more important in ensuring market credibility. In her research she finds that carbon markets after Paris might produce new transparency challenges and may increase the risk of carbon fraud. The perceived risk of double counting has been prominent. Due to double counting, the voluntary market faces an 'identity crisis' as it might no longer be compatible with the international climate regime. Franke et al. [2020] research the feasibility of two distinct blockchains, a public and permissionless blockchain (Ethereum) and a private and permissioned blockchain (Hyper-ledger Fabric) for the Paris Agreement carbon market mechanism. They recognize the interdependency between the technical structure and case requirements, the number of users, and their rights in the system. Their results show that both blockchain systems can address present compliance carbon market constraints by enhancing market transparency, increasing process automation, and preventing double counting.

Schneider et al. [2020] identified and categorized environmental integrity risks of international carbon market mechanisms and ways to overcome them under the Paris Agreement. Robust accounting is brought forward as a key prerequisite out of four approaches, but the writers ask for more research in the feasibility and practical implementation of the four broad approaches they identified. Schneider et al. [2020] address the question under the Paris Agreement if mitigation outcomes from sectors and GHGs that are not covered by NDCs should be allowed for international transfer and use towards another country's NDC and how they should be accounted for. Their paper outlines key issues and options relating to these questions, raising issues of capacity, fairness, breadth of mitigation, and incentives for making progress in the scope and ambition of NDCs over successive NDC cycles.

Lang et al. [2019] analyse the perceptions to the new regulatory environment within the voluntary carbon market, identifying two thought spaces for the future voluntary carbon market. Below a summery of the literature is provided, with markings on discussed subjects from which six articles mostly discuss carbon market mechanisms and double counting as one of the main quality issues. Only the article of Franke et al. [2020] researches the application of blockchain as a solution in the carbon market for the Paris Agreement mechanism. Five out of seven articles too focus on the compliance market and double counting with respect to the Nationally Determined Contributions, leaving little literature focusing on the voluntary market. Another thing to notice is that all articles refer or discuss to the Paris Agreement to some extent.

Three general categories become apparent when looking at the selected research. Research that focuses on identifying Market Integrity risks [Schneider et al., 2018; Lang et al., 2019; López-Vallejo, 2022]. The second category focuses on Solutions for market integrity [Franke et al., 2020] and lastly exploration of potential market design [Lang et al., 2019; Schneider et al., 2020].

1.2.6 Blockchain Technology Used to solve Double counting

Searching directly for the applicability of blockchain for double counting only three articles appear, from which one was the already identified article of [Franke et al., 2020]. The article of Suankaewmanee et al. [2020] applies blockchain to a data management framework for the energy market. The last article provides a policy framework based on blockchain for a road-transport based ETS [Li et al., 2021]. The research showed that the blockchain-based road-transport ETS system was found to outperform other forms of ETS on criteria of acceptability, feasibility and environmental performance. Evident from these results is that there is currently little research on the application of blockchain technology specifically aiming to solve double counting within the context of carbon markets.

1.2.7 Blockchain Technology Applied in Carbon markets

What can be deduced from the extant literature is that the concept of applying blockchain to enhance carbon trading is not new. Many articles focus on the concept of blockchain to improve ETS's. For example, Khaqqi et al. [2018] proposed a novel ETS model supported by blockchain technology and a reputation-based trading mechanism to improve ETS efficacy. However, the distributed form of the blockchain nodes in their proposed ETS is unclear and it lacks a consensus mechanism. Fu et al. [2018] presented a blockchain-enhanced ETS framework in the fashion apparel manufacturing industry, which demonstrates how carbon emissions could be easily measured and recorded with less human labour.

Mandaroux et al. [2021] focuses on the European Emissions Trading system in which they propose to digitalize the system by a distributed ledger technology, enabling the verification of authenticity and provenance, proof of ownership, and lifecycle traceability of carbon certificates and assets. Hartmann and Thomas [2020] designed a conceptual blockchain model for the Australian carbon market. An integration model of blockchain-based peer-to-peer trading in the energy and the carbon emission market is given by [Hua et al., 2020].

They claim that the purchase of carbon allowances constitutes a part of the energy costs, and an efficient decentralized trading platform is therefore required to enable prosumers to trade energy and carbon allowances together. Hu et al. [2020] proposes a Blockchain-enabled Distributed ETS (BD-ETS) to improve the security and efficiency of the system. The BD-ETS transforms the centralized Carbon Emissions Permit trading mode to a distributed trading system based on a smart contract performed in Hyperledger Fabric. Galenovich et al. [2018b] provides a design to 'blockchainaize' the implementation of Article 6 of the Paris agreement, with the intent to use a public blockchain.

From the literature a several clusters appear: industry 4.0, where the [Fu et al., 2018; Khaqqi et al., 2018], Specific market ETS models [Hartmann and Thomas, 2020; Mandaroux et al., 2021] and general ETS models [**?**Hu et al., 2020; **?**] These categorizations can be made under the umbrella distinction of permissoned and permissonless blockchain models, in which permissioned blockchain models are far greater in numbers in the literature. Additionally, what can again be observed is that most literature is focused on the compliance market.

1.2.8 Theoretical Frameworks to Evaluate Blockchain Designs

Sinha and Chowdhury [2021] developed a framework based on an ontology-driven-blockchain-design approach and value chain analysis of international trade. The framework is specifically based on global trade and roles of exporters and importers. Pizzi et al. [2022] evaluate blockchain's enabling role for sustainability reporting. Rukanova et al. [2021b] focus on realizing value from voluntary business-government information sharing through blockchain-enabled infrastructures. For their case study they adapted the framework of van Engelenburg et al. [2020] to analyse the link between technical design choices and value. Sonmez et al. [2021] developed a framework to evaluate design decision choices of blockchain from a project management perspective. This framework however has no ties to the governance and therefore the stakeholder context.

Considering the extant literature it becomes evident that the framework of van Engelenburg et al. [2020] is the only framework that explicitly connects the high-level stakeholder relations, with governance requirements towards design-choices. Due to the complex nature of the voluntary carbon market in which Rabobank Acorn is embedded, the framework of van Engelenburg et al. [2020] is the framework to generate an in-depth understanding of the Rabobank Acorn case.

1.3 KNOWLEDGE GAPS

The demand for carbon offsetting is rapidly growing and voluntary carbon markets have emerged in velocity. Growing pains are however accompanied with the speedy development of the market. While the potential of the voluntary carbon market is clear, quality, governance and accounting issues such as double counting, non-additionally and lack of standardization remain [Blum, 2020; Kollmuss et al., 2008; López-Vallejo, 2022; **?**; Lang et al., 2019; Schneider et al., 2014]. One of the leading quality issues is double counting. Several reports discuss what double counting is, the different shapes in which it can present itself and how the market structures enable double counting [Schneider et al., 2014; Kollmuss et al., 2008]. It becomes evident from the extant literature that double counting is an intricate issue, not possible to be solved by just one actor. Despite these reports discerning the issue of double counting as well as other market issues. Clear, uniform oversight of the market mechanisms related to double counting seems to be missing. This leads to the first knowledge gap: A comprehensive overview of the carbon market mechanisms, discerning between compliance and voluntary carbon markets, influencing and related to double counting is lacking, as well as a theory that synthesises these interrelationships.

This thesis aims at providing this insight by providing an overview of said market mechanisms, which form the scientific foundation for the mechanisms influencing the issue of double counting experienced in the carbon market.

Meanwhile, Blockchain technology is seen by various parties as suitable to improve the monitoring, reporting verification processes in the carbon markets [Kim and Huh, 2020; Franke et al., 2020; Li et al., 2021; Mandaroux et al., 2021]. In response, many articles and reports provide high-level blockchain architectures [Khaqqi et al., 2018; Kim and Huh, 2020; Li et al., 2021]. However, all of these blockchain solutions have been designed for the compliance market. The compliance market is noticeably different from the voluntary market. Firstly, the compliance market is significantly more mature than the VCM, which is demonstrated by its sound rules and regulations. Whereas the VCM lacks unilateral accounting standards and strong regulation. Although the solutions proposed in the literature for the compliance market illustrate how blockchain solutions should be designed, these solutions cannot be directly transferred to the VCM. Hence, despite researchers acknowledging the possibilities blockchain technology has to offer for carbon markets in general, little research has been pursued in the area of the VCM. This leads us to the second knowledge gap: Research on the possibilities for blockchain in the VCM is scarce. Technical and governance-related requirements to realize the value of blockchain technology for the VCM remains unclear, especially regarding double counting.

This thesis aims to fill this gap by gathering rich empirical data from a project developer in the VCM. If possible, additional data is gathered from other market actors as well. Such empirical insights can identify best practices for blockchain design choices, governance requirements and stakeholder dynamics, and provide insight into the main challenges in developing blockchains specific to the issue of double counting, seen from a blockchain-based systems perspective.

Lastly, by researching blockchain design frameworks only two specific frameworks provide the ability to taxonomize blockchain designs or applications, in the bigger context of governance requirements linking influences on the stakeholder dynamics. One framework focuses more on the realization of value, through design choices and less on the stakeholder context. Hence, the novel framework of van Engelenburg et al. [2020] is adopted to provide guidance in the research analyzing Acorn's blockchain solution. So far, such frameworks have been based on the analysis of private blockchains and not yet on public blockchains van Engelenburg et al. [2020]. The enriching and increasing of robustness of such frameworks ask for additional empirical research, from which new knowledge can be added. This leads to the third knowledge gap: The lack of exhaustive linking in blockchain evaluation frameworks between stakeholder dynamics and design choices of blockchains placed in their socio-technical systems. Combining the gaps above identified from the literature reaps the following research question formulated below.

1.4 MAIN RESEARCH QUESTION

The thesis dives into blockchain-based platform solutions by exploring their potential to solve double counting in the VCM. This research domain is underdeveloped, as such the study undertakes the initial step of evaluating a blockchain-based platform solution against the requirements of double counting. More insight into double counting, the mechanisms of (voluntary) carbon markets, and its interdependencies are required. To support this evaluation, a framework is required that enables the simultaneous evaluation of IT infrastructure, inter-organizational governance as well as societal interactions. A suitable technology could provide the additional transparency, traceability, and alignment required in the VCM. This is captured in the following main research question:

What framework can be developed to evaluate the benefits and limitations of blockchain-based platforms to prevent double counting in the voluntary carbon market?

1.5 RESEARCH OBJECTIVE

In line with the research objective to: *'propose an extension of the framework of van Engelenburg et al. [2020] that fills the knowledge gap identified in the extant literature to prevent double counting, of the lack of frameworks suited for the systematic mapping of the stakeholder context and analysing how this influences design choices and requirements. The framework should guide project developers and other VCM actors in designing and evaluating adequate blockchain-based systems to track carbon credits and organize their processes in such a manner that double counting can be prevented.'*

First, the research tries to expand the literature on double counting in the VCM, identifying the possible forms of double counting experienced in the empirical context and classifying these in a comprehensive scheme. Second, the research on employing blockchain technology to prevent double counting in the VCM is considerably scarce. Literature focused on public blockchains was even more scarce. Therefore, one of the main objectives of the research is to explore the potential of (public) blockchain technologies to achieve the required transparency, traceability, security and immutability in carbon offsetting. By adopting the framework of van Engelenburg et al. [2020] as a starting point for the evaluation of a blockchain solution of a recognized project developer and market enabler in the carbon market, the thesis dives into the research on (public) blockchain solutions by researching their role in preventing double counting in the VCM. By doing so, the gap identified in VCM research can be bridged and double counting can be better addressed.

Furthermore, the research aided the development of a multi-level governance blockchain evaluation framework through performing the case study. The case study provided insights into the limitations of van Engelenburg et al. [2020] her blockchain evaluation framework when it was applied to the complex multi-level stakeholder context of carbon markets. These insights formed the bases of the the multi-level governance blockchain evaluation framework, which integrates the blockchain evaluation model of van Engelenburg et al. [2020] with multi-lever governance literature [Shigaeva et al., 2013] and, with empirical insights on additional blockchain design points of blockchain-based platforms that make use of tokenization. Therefore, this thesis tries to fill the gap in the extant literature by facilitating an exhaustive and adequate evaluation of blockchain solutions in multi-level, socio-technical contexts.

Additionally, the research provides insights into the processes and governance structure of the Acorn Program from Rabobank, who shared valuable, detailed information and expert knowledge throughout the research. As Acorn operates in the voluntary carbon market they are committed to increasing the overall market quality by example in their role of project developer and market enabler, the findings from the research on preventing double counting provides scientifically grounded propositions to improve Acorn's processes by employing innovative technologies. It also provides Acorn with a deeper understanding of the influences from the wider social-technical context and how these relate to Acorn's information systems.

Lastly, the research provides a starting point for companies, embedded in a multi-level stakeholder context, to reason about contextual influences and considerations, if they want to employ blockchain technology to create transparency, traceability, and security in their supply chains and asset life cycles.

1.6 RESEARCH SUB-QUESTIONS

From the main research question related sub-questions are deduced. Firstly, before one can explore solutions the specific issue of double counting encountered in the broader context and by the unit of study have to be clarified. An introduction on the carbon markets and double counting is given based on existing literature, after which multiple interviews were held with the strategy lead of the case to gather insights from the empirical environment.

Based on these findings, a general overview of the mechanisms on which carbon markets are based, its market players and institutional rules is presented. Building on this, a clear description of double counting for Acorn and the global markets is presented. This results in answering the first sub-question:

1: What is the problem of double counting taking on both a broader stakeholder and Acorn specific perspective?

Understanding the context of carbon markets and the issue of double counting guided by the theoretical framework, provides a basis for directing the research towards the social unit of analysis of the case study. First, the applicability for blockchain in the carbon market is discussed based on the extant literature. Next, based on the benefits and limitations identified from the literature review, design configurations were identified which leads us to the second sub-question:

2. What are the key features, benefits and limitations of blockchain architecture with respect to the prevention of double counting?

The research aims to study the blockchain solution of Acorn in-depth, to gain a broader understanding of double counting might be solved and to explore how their envisioned configuration could spillover towards the global market. The case study method is employed to gain this understanding and in this phase the framework of van Engelenburg et al. [2020] is drawn upon to guide the data collection process in acquiring the necessary information to generate valid theory. This leads us to the next sub-question:

3: What are the benefits and limitations of Acorn's blockchain solution which can be identified by applying the framework of van Engelenburg?

The interpreting of the data leads to the following sub questions related to both the unit of study as well as the model used for analysis.

4: How does the Acorn solution contribute to addressing the wider problem of double counting, adopting the wider stakeholder perspective and what are additional aspects that remain to be addressed to achieve an industry solution?

After analyzing the data and having found patterns or emerging themes, these have to be interpreted. One of the first steps is addressing the implications the model has for the framework of van Engelenburg et al. [2020], as the case study findings can have implications both for theory development and theory testing. They may establish, strengthen or weaken historical explanations of a case and possibly allow theoretical generalization beyond the particular cases studied Crowe et al. [2011].

5: What extension or adaption can be proposed to the model of Van Engelenburg based on the case analysis of Acorn?

The last step is the adequate reporting of the processes followed in the case study, providing the reader with enough context to understand the methods used and how conclusions were reached. The analytical narrative should be strong to make a convincing argument. This last part allows for the combining of the answers to the previous sub-questions and answering the main research question. To conclude, through analysing the issue of double counting as well as the solution space for technical interventions valuable insights are gained.

Table 1.1 provides an overview of the sub-questions, research strategies applied to address them and corresponding deliverables.

Table 1.1: Methods used to answer each sub-question and related deliverales

Research Question	Methods Used	Deliverable
1: What is the problem of double counting taking on both a broader stakeholder and Acorn specific perspective?	Desk Research & Interviews	Overview of Double Counting, Mapping of relevant Actors
2. What are the key features, benefits and limitations of blockchain architecture with respect to the prevention of double counting?	Desk Research	Core Concepts Blockchain
3. What are the benefits and limitations of Acorn's blockchain solution which can be identified by applying the framework of van Engelenburg?	Semi-Structured Interviews, Document Analysis & Workshops	Overview of Benefits & Limitations Blockchain Solution
4. How does the Acorn solution contribute to addressing the wider problem of double counting, adopting the wider stakeholder perspective and what are additional aspects that remain to be addressed to achieve an industry solution?	Semi-Structured Interviews, Document Analysis, &Workshops	Assessment of Suitability based on findings Table Remaining Questions
5. What extension or adaption can be proposed to the model of Van Engelenburg based on the case analysis of Acorn?	Theory building	Framework developed from case analysis

1.7 SCOPE OF THE RESEARCH

The scope of the research refers delineates the extent to which the research area will be explored in the work and specifies the boundaries of the research. Adequate scoping helps the researcher to attain the research objective and answering the research questions.

This thesis focuses on carbon removal and sequestration projects, specifically on nature-based projects in the field of agroforestation. Including both reduction as well as removal offsetting projects is unrealistic since these projects differ profoundly in its core characteristics, which would make the scope of the thesis too big for the available research resources in the allotted time.

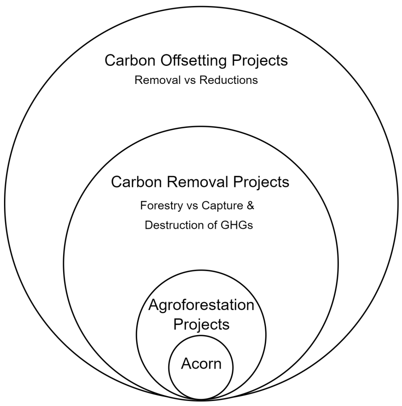

Figure 1.1: Scope of the Research

1.8 SOCIETAL RELEVANCE

The thesis focuses on assisting project developers, NGO's, standard registries and policymakers with improving the quality of the information sharing & accounting systems. As discussed, the MLGBE framework can be used by these agents to reason about potential blockchain solutions and identify requirements and limitations of information systems related to the tracking, tracing and trading of carbon credits. Improved, blockchain-based, information systems can reduce double counting from occurring whilst increasing overall security, transparency and quality in the market. According to the literature, enhanced transparency is crucial for the VCM to move forward [Adams et al., 2021; Blum, 2020; Lang et al., 2019].

The thesis, by identifying the opportunities and limitations of (public) blockchain-based systems for the tracking, tracing and trading of carbon credits in the VCM, aims at enabling market actors to access reliable information. The traceability allows actors to monitor and manage the entire supply chain system and carbon credit system processes [Wang et al., 2020]. As a result, the efficiency, credibility and consistency of carbon emission practices can be improved at a supply chain level [Ashley and Johnson, 2018; Segers et al., 2019; Wang et al., 2020].

Finally, the research output can encourage parties with a monitoring role to reap the benefits of the data produced throughout the supply chain of carbon credits. The carbon markets are in need of returning to the basics of carbon removals by stripping away complicated accounting procedures. As stated by Krabbe et al. [2015], corporate climate action is increasingly important in driving the transition towards a low-carbon economy. To illustrate, under the mitigation scenario for 2035 global upstream scope 3 emission intensities need to be reduced by an additional 54% compared to a baseline scenario with reference technology [Li et al., 2019]. Promoting the prevention of double counting by making insightful the shortcomings of current market standards and the opportunities for blockchain-based information sharing solutions, can incentivize private and public agents to drastically revise current accounting standards. Overall, increasing the impact of the carbon markets.

1.9 THESIS OUTLINE

Figures 1.2 presents the thesis outline. The research steps have been visualized below in the research flow diagram. The Diagram shows the four main phases which have to be completed during the research from beginning to end. The diagram presents the main deliverables of each chapter on the right side of the figure.

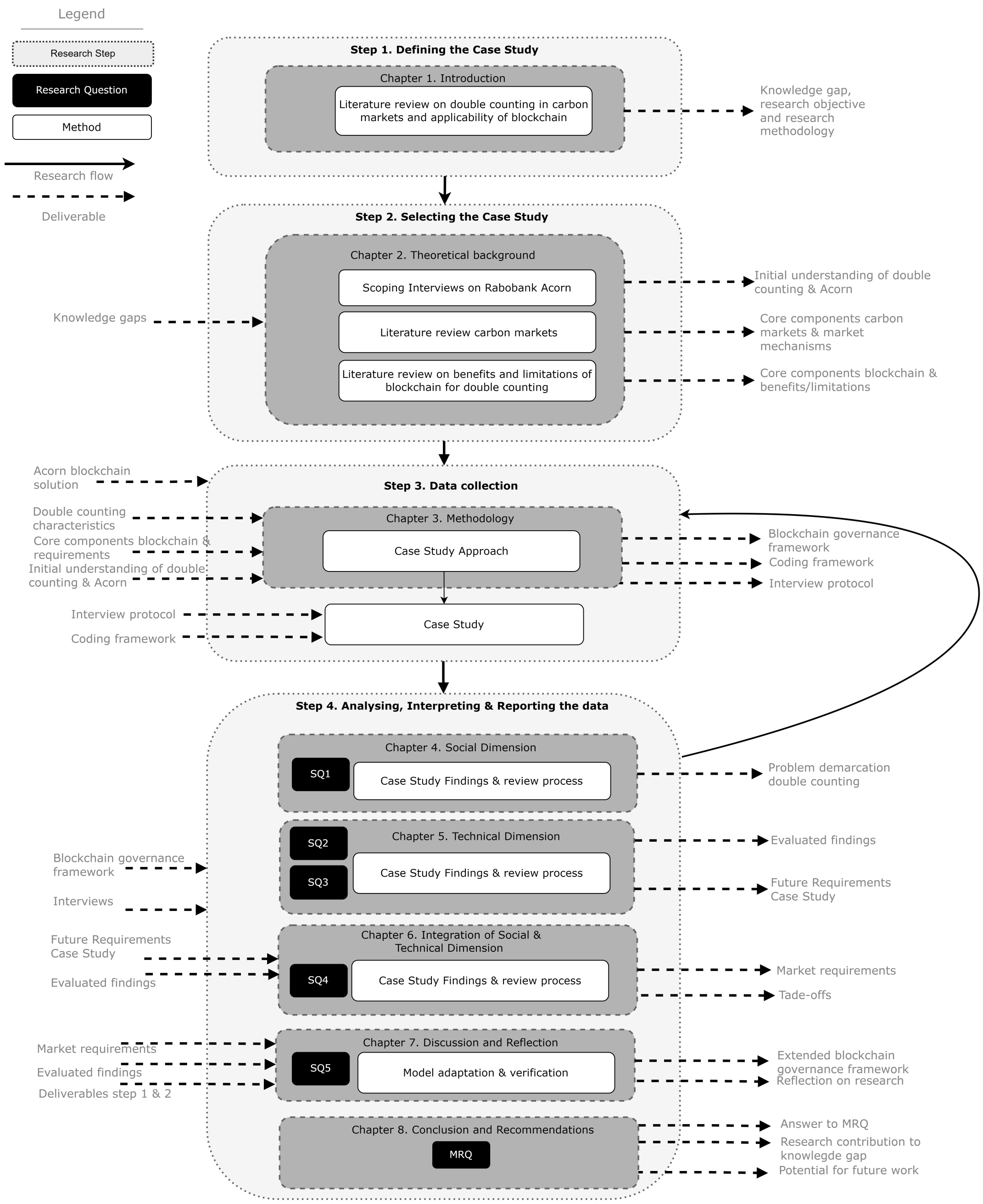

Figure 1.2: Research flow diagram

2 THEORETICAL BACKGROUND

Chapter 1 provided a brief overview of the problem domain, introducing the VCM and the possibility of double counting. Carbon markets are complex in nature, they consist of many actors accompanied by differing rules and regulations. For the uninformed reader, the topic of the research presented in the thesis can be challenging to grasp. Especially, because the thesis integrates the complex domain of carbon markets with innovative technologies as blockchain. An understanding of several aspects related to carbon markets and blockchain technology are crucial for the inexperienced reader to appreciate the depth of the findings of the thesis. Hence, this chapter was drafted to provide a synopsis of carbon markets, including how carbon markets came to be and clarification of the asset that is traded in carbon markets. The second half of the chapter, gives an overview of the basics of blockchain technology, to introduce blockchain design choices and introduce the reader to the tokenization of assets. Experts in the field can opt to skip this chapter and move directly to the research methodology in Chapter 3

The chapter starts with a brief overview of the core mechanisms of carbon markets in Section 2.1. Section 2.1 describes what offset projects are and how the quality of these projects are measured. Next, it describes the life-cycle of a carbon credit and provides an overview of the different type of carbon offset projects.

Subsequently, the concept of carbon accounting is discussed in section 2.2. The possibility to double count exists due to the underlying principles of carbon accounting. Carbon accounting has an important role in the current carbon markets and without carbon accounting climate mitigation measures could not have come into existence. The section on carbon accounting also dives deeper into emission scoping, which is adhered to by companies to disclose on their emissions. Three different scopes are distinguished to clarify the reporting of all emissions. Scope 1 are direct emissions resulting from a companies' production processes, Scope 2 are indirect emissions related to the production process and Scope 3 includes all other indirect emissions that occur in a company's value chain.

As the research considers the life-cycle of a carbon credit a supply chain, the distinction between transparency and traceability is made (Section 2.5) as they differ slightly and it is important to understand this difference. In a supply chain context, transparency refers to information available to companies involved in a supply network. In parallel, supply chain traceability is the ability to identify and verify the components and chronology of events in all steps of a process chain.

Lastly, the basics of blockchain technology are discussed in Section 2.7. Blockchain technology generally possesses the key characteristics of decentralization, persistency, anonymity, and auditability. Specific functionalities like smart contracts and asset tokenization are further touched upon in Section 2.7.5 and Section 2.7.6. In a nutshell, a smart contract is executable code that runs on the blockchain to facilitate, execute and enforce the terms of an agreement between untrusted parties. Asset tokenization is generally the process of representing a given (financial) asset as a unit on the distributed ledger, a representation maintained by the individual nodes running versions of the blockchain client software.

2.1 CARBON MARKETS AND OFFSET PROGRAMS

Carbon markets enable countries, organisations and individuals to purchase certificates of emission reductions produced elsewhere to compensate their greenhouse gas emissions [Blum, 2020]. Carbon markets can either trade quotas or credits. Allowances are units of quota issued by the government, or tradeable, bankable entitlements to emit [Poolen and Ryszka, 2021]. In such a system an overall cap is set to achieve emissions reductions. Credits are certificates created when a person or an entity under utilizes a 'right' to pollute or creates an opportunity to capture carbon. In credit systems there is no finite supply of credits, new credits are generated with every new project implemented. The first system, based on an finite number of allowances is commonly referred to as cap-and-trade systems and the latter, based on the trading of credits, are baseline-and-credit systems.

This thesis will only focus on baseline-and-credits and not allowances, since the allowances, part of the compliance market, are generally well accounted for and are generally not fallible to double counting. However in order to understand the market mechanisms impacting the carbon market, the allowance cap-and-trade mechanisms will be shortly touched upon later.

The definition of an offset is given by the World Bank as cited in López-Vallejo [2022] is as follows, *"An offset is a mechanism compensating for emissions by investing in environmental projects beyond regulated participants or in other market jurisdictions"*. Note that offsetting is project based, and that these environmental projects reap offset credits, which is a *"transferable instrument certified by governments or independent certification bodies to represent an emission reduction of one metric tonne of CO2, or an equivalent amount of other GHGs"*.

Carbon markets generally include the global project-based carbon offset markets: the Kyoto Protocol's Clean Development Mechanism (CDM) (though the CDM is not always recognized), the upcoming mechanisms under Article 6 of the **pa!** (pa!), and the voluntary carbon market. Within offset programs, quality is fundamental to maintaining market integrity and overcoming problems. The quality of projects is generally measured by how well they prevent practices of several core principles: *non-additionally*, *overestimated supply*, and *permanence* [López-Vallejo, 2022].

- **Additionally** means that a project needs to demonstrate that it complements other efforts and that the intervention would not have happened without offset funding [López-Vallejo, 2022]. Simply put, a project is additional when it is prompted by an offset program, not by policies or other factors [López-Vallejo, 2022]. The topic of 'additionality' is the most fundamental and contentious issue in the carbon offset market [Kollmuss et al., 2008]. Even now, additionality remains difficult to determine in practice. *Many different tools have been developed to maximize the accuracy of additionality testing and to minimize the administrative burden for the project developer.*

- **Overestimated supply and leakage** can be problematic in three ways, overestimating the Greenhouse gas (GHG) emissions reduction, lack of quality projects which grant socio-environmental co-benefits and lastly, not having enough projects for the offset programs. Over-estimation occurs when the baseline is miscalculated and it establishes more potential reductions than they really are [López-Vallejo, 2022].

  In other words, it represents the counterfactual scenario of what would have happened if the offset project had not been implemented. The number of credits generated by the project is equal to the difference between emissions in the baseline scenario and emissions resulting from the project. The key difficulty is that the baseline scenario is hypothetical; by definition, it describes another reality, one in which the activity is not implemented as an offset project. As the baseline scenario will never occur, there is no foolproof way to divine with certainty what the results of that scenario would have been [Kollmuss et al., 2008].

- **Leakage** is of particular concern in Land Use, Land-Use Change and Forestry projects. Leakage is the unanticipated loss of carbon reductions outside the project boundary. For example, the reforestation of pastureland may drive local farmers to clear forests elsewhere for new pastures. Leakage can best be addressed through careful project design.
- **Permanence** is the question of whether projects maintain GHG reductions or removals on a permanent basis, in which case they must have specific requirements stretching over multiple decades and a comprehensive risk mitigation and compensation mechanism in place, with a means to replace any units lost.
  Permanence refers to the length of time that carbon will remain stored after being sequestered in vegetation. Forests can easily be destroyed by natural events such as fire, pests, or disease, or by illegal logging or burning. Land Use, Land-Use Change and Forestry projects can therefore only temporarily sequester carbon from the atmosphere.

Together these principles determine the quality of an offset project. Quality of projects is an important pillar in the carbon market, because if trust in the market diminishes due to contested quality, the legitimacy of using market approaches to address climate change is lost and carbon credit prices will drop. Such issues will be further addressed in section 4.1. One of the difficulties in understanding carbon offsetting, trading and carbon markets is that the instances traded are intangible, making it harder to grasp the underlying mechanisms. Hence, the next section will provide an overview of how the carbon credits are generated, issued and traded.

2.1.1 Life-cycle carbon offset credit

To gain a better understanding of the traded instances in a carbon market a detailed presentation of the lifecycle of a carbon offset credit is provided. The lifecycle presented in figure 2.1 is based on a carbon offset in the voluntary market.

Figures 2.1 presents the common lifecycle of a carbon offset credit.

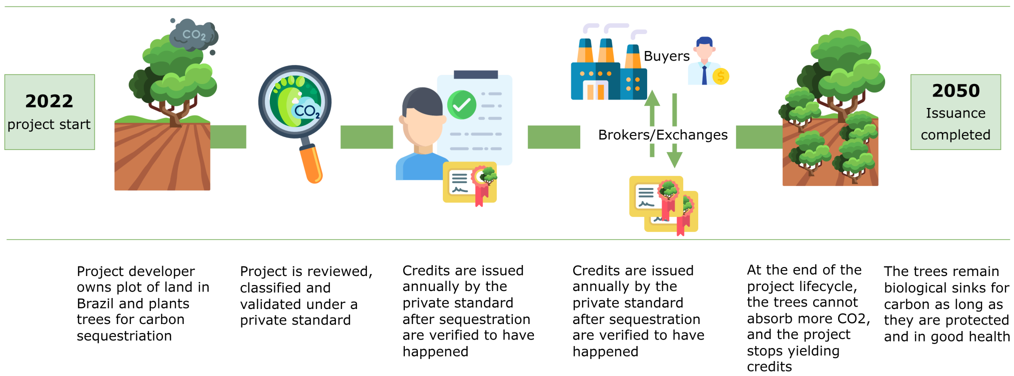

Figure 2.1: Carbon offset credit lifecylce adapted from Adams et al. [2021]

The offsetting project starts with *(1) methodology development*. To certify GHG reductions, they must be shown to meet carbon offset quality criteria. This requires a methodology or protocol specific to the type of offset project pursued. Generally carbon offset programs posses a library of approved methodologies covering a wide range of project types. Yet, project developers may propose new methodologies for approval [Broekhoff et al., 2019b]. When an approved methodology is in place the project can start.

As can be seen in figure 2.1 the project is designed by a project developer, possibly financed by investors. Next, the project needs to be *(2) reviewed, classified and validated* by an independent verifier and be registered with a carbon offset program. This registration ratifies that the project is legitimate, has been approved by the program and eligible to start generating carbon offset credits after starting operations.

In step (3) the project is implemented, monitored and will be periodically verified to determine the quantity of emission reductions it has generated. The length of time is typically one year between verifications. A carbon offset program approves verification reports, and consecutively issues the corresponding carbon credits, which are usually deposited into the project developer's account in a registry administered by the offset program [Broekhoff et al., 2019b].

Logically, the *(4) transfer of offset credits* follows. The issued carbon offset credits can be transferred into different accounts. Transfers are usually undertaken as a result of a purchase or trade. The offset credit buyers can either choose to use the offset credits by retiring them, hold them, or transfer them to another account. Offset credits may change hands multiple times before they are ultimately retired and used. When credits are retired, the credit is taken of the market and never to be traded or swapped again.

Carbon credits used for offsetting reasons can be used for different purposes:

- In some compulsory carbon tax or ETS initiatives, carbon credits from the voluntary market are allowed to offer regulated companies some flexibility for compliance.
- In the voluntary carbon market, credits can be used to offset individual and organizational emissions on a voluntary basis, e.g. to reach their CSR goals or their voluntary climate goals.
- Countries can trade credits to achieve their Nationally Determined Contribution NDCs targets. NDCs are at the heart of the Paris Agreement of 2016 and its long term goals United States Framework Convention on Climate Change (UNFCCC). The Paris Agreement requires each party to prepare, communicate and maintain nationally determined contributions NDC that it intends to achieve.

As mentioned, carbon credits are generated through carbon offsetting projects. These carbon offsetting projects vary in nature and can be generally grouped in two main categories: (1) avoidance and reduction projects and (2) removal or sequestration credits. Avoidance/reduction projects reduce emissions from current sources, such as by funding the implementation of lower-carbon technologies like renewable energy, and avoiding practices that cause emissions , e.g.by reducing deforestation. Removal/sequestration projects take out and use/store CO2 from the atmosphere, including through nature-based sequestration such as reforestation, peatland restoration, and technology-based removal like bio-energy with carbon capture and storage and direct air capture with carbon capture and storage [Adams et al., 2021].

Figures 2.4 provides an overview of the avoidance/reduction vs removal/sequestration project types.

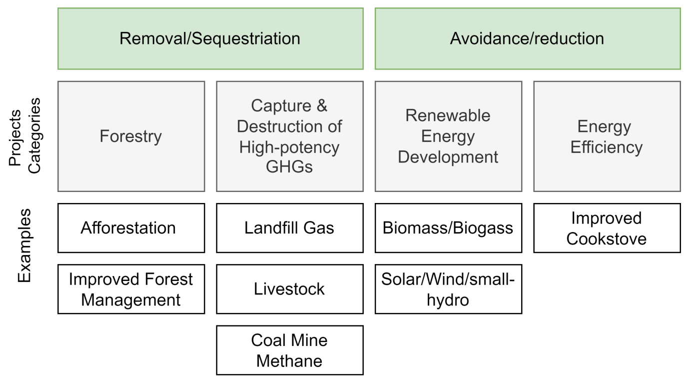

Figure 2.2: Overview of Carbon Offset Projects adapted from Greenhouse Gas Management Institute and Stockholm Environment Institute [2020]

Projects that aim to reduce GHG emissions from land use practices are collectively called Land Use, Land-Use Change and Forestry activities. There are three broad types of Land Use, Land-Use Change and Forestry projects:

- Those that avoid emissions via conservation of existing carbon stocks (i .e . avoided deforestation), called Reduced Deforestation and Degradation (REDD)
- Those that increase carbon storage by sequestration (afforestation and reforestation)
- Those that increase carbon storage by soil management techniques (e .g . no-till agriculture

2.2 CARBON ACCOUNTING

Carbon accounting has become an enabler of climate mitigation measures, including national emission limitation commitments, corporate climate change performance targets and carbon markets [Ascui and Lovell, 2011]. Ascui and Lovell [2011] emphasizes the important of the role and contribution of carbon accounting, drawing attention towards the different manifestations of carbon accounting which tend to have their own institutions, normative practices and distinctive discourse. He argues that no single definition of carbon accounting can be given whilst recognizing the jumbled landscape created by the collisions within and between multiple frames. They identify five frames of carbon accounting, namely *(1) physical carbon accounting, (2) Political carbon accounting, (3) Market-enabling carbon accounting, (4) Financial carbon accounting, and (5) Social/environmental carbon accounting.*

Physical accounting is natural sciences view of carbon accounting as a matter of physical measurement, estimation or calculation and attribution of greenhouse gas fluxes through the biophysical environment.

Political accounting takes a step away from the scientific mode of measurement, calculation and estimation of greenhouse gas emissions at the global level, towards a function of monitoring and reporting at the national level.

Market-enabling accounting is found in the global market in greenhouse gas emission rights, driven by emission obligations. Originated from the individual caps on developed countries' greenhouse gas emissions in the Kyoto Protocol, linked by the three 'flexibility mechanisms' of ETSs, Joint Implementation (JI) and CDM [Ascui and Lovell, 2011].

2.2.1 Emission Scoping

Credible corporate climate commitments begin with setting emission reduction targets that cover both the companies' direct and indirect GHG emissions. Aligning such a target's ambition level with the level of decarobonization required to limit global warming to well below two degrees Celsius is widely seen as best practice. To achieve the required emissions reductions, companies can pull levers such as improving energy efficiency, transitioning to renewable energy, and addressing value chain emissions. The next step involves companies committing to a target that may involve the use of voluntary carbon credits of carbon markets, either to compensate for emissions that have not been eliminated yet or to neutralize residual emissions which cannot further be reduced.

The emissions to offset, discussed in the previous sections are all part of a companies' activities. For example, the emissions emitted from the production of fabrics, medicine, computer chips and any product one can think of. For companies to correctly account for these emissions, standardization and categorization have to be in place. This is where emission scoping for the corporate sector comes in.

Figures 2.3 gives an overview of the emission reduction scoping.

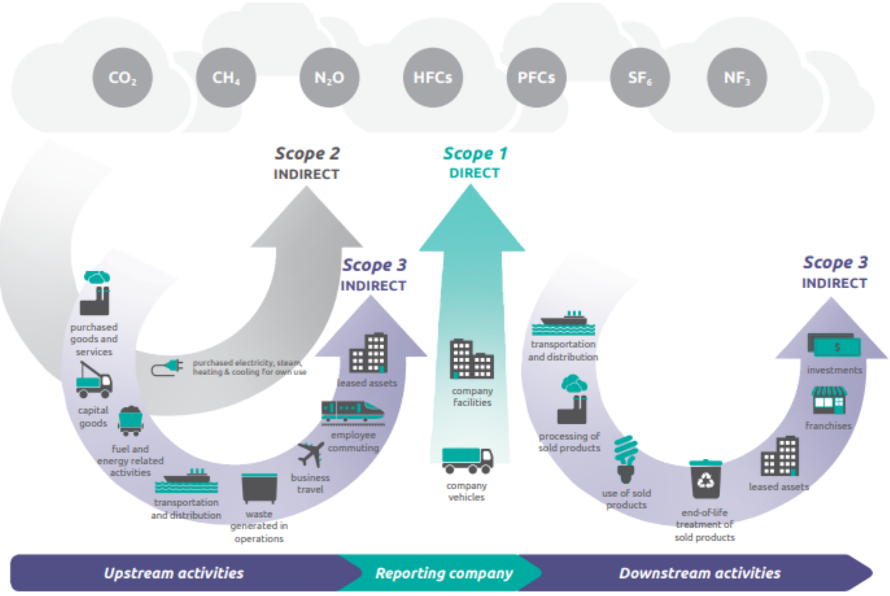

Figure 2.3: Overview of Scope 1,2 & 3 emissions from GHG Protocol and Carbon Trust Team [2013]

Figure 2.3 shows that there are three ways a business or organisation emits greenhouse gases and carbon through the use or consumption of energy, which are referred to as 'scopes' in the carbon sector. Scope 1 emissions are direct from owned or controlled sources. Scope 2 emissions are indirect emissions from the generation of purchased electricity, steam, heating and cooling consumed by the reporting company. Scope 3 includes all other indirect emissions that occur in a company's value chain. The fifteen categories which can be seen in scope 3 are intended to provide companies with a systematic framework and are designed to be mutually exclusive to avoid a company double counting emissions among categories [Greenhouse Gas Management Institute and Stockholm Environment Institute, 2020]. So far, companies have generally focused on reducing scope 1 and 2 emissions. Yet, the greatest emission reduction opportunities lie in the scope 3 emissions going forward, given that on average the Scope 3 emissions are 5.5 times the amount of combined Scope 1 and Scope 2 emissions [Shrimali, 2021].

Therefore, whilst the focus has previously been on Scope 1 and Scope 2 emissions, the focus has started to shift to scope 3 emissions, not only for assessing the carbon risk of the supply chain but also to hold business entities responsible for the whole supply chain. Ensuring that carbon emissions of a business entity are not simply pushed to other parts of the supply chain Shrimali [2021]. Whilst the process of calculating Scope 1 and Scope 2 emissions is well established, the same is not yet true for scope 3 emissions, despite of the many efforts by a multitude of coalitions and industry actors.

2.3 COMPLIANCE MARKETS

Historically, ETS and corresponding offset programs were designed on a global scope in the 1990s by the United Nations through a regime supported by the UNFCCC and Kyoto Protocol [López-Vallejo, 2022]. The Kyoto Protocol allowed for the acquisition of Certified Emission Reductions through three market-based instruments [Gallo et al., 2016]:

- Emission trading systems
- Clean Development Mechanism and,
- Joint Implementation

Offsets work when actors pay an extra quota to compensate for greenhouse gas emissions from specific projects or standards. They can compensate for individual or companies' entire pollution or for specific sector caps. It functions through companies making up for its emissions for instance by financing reforestation, transportation, ecotourism, agriculture, waste, buildings or clean energy projects elsewhere. Offset programs perform three basic functions [Broekhoff et al., 2019b]:

1. *Development and approving standards that set criteria for the quality of carbon offset credits;*
2. *Reviewing offset projects against these standards (generally with the help of third-party verifiers*
3. *Operating registry systems that issue, transfer, and retire offset credits.*

Offset programs range from international intergovernmental to those run by national or subnational governments and to voluntary efforts, generally operated by non-governmental organizations (NGO's). From these programs, some are independent and some are linked to ETS with cap-and-trade systems.

The most important international and intergovernmental offset programs are the CDM and the Joint Implementation program through the Kyoto Protocol. The treaty established three different responsibilities for three categories of signatory states, namely developed countries, developed countries with special financial responsibilities, and developing countries. The develop countries are originally referred to as Annex 1 countries. The CDM protocol offered Annex 1 countries offset projects to achieve their target reductions.

The offset projects encouraged the development of climate-mitigation projects in other nations. Under both the CDM and JI, polluting countries paid for these projects. ETSs and cap-and-trade systems deliver exact levels of emissions reductions by enforcing non-compliance penalties. This helps offer jurisdictions predictability when it comes to advancement toward their targets. The EU pioneered the use of ETS and offsets, putting their ETS in to place to comply with its KP commitments. Together, these programs accounted for the majority of offsetting practices worldwide. Criticism against the mechanisms under the Kyoto Protocol included the lack of transparency during the implementation and validation of mitigation activities Franke et al. [2020]. After these issues presented itself under the framework of Kyoto, the Paris Agreement followed as a successor to the Kyoto Protoco lposing as a new and improved version.

2.3.1 Paris Agreement

The Paris Agreement rose from the 21st conference of parties of the UNFCCC. The Paris Agreement, like the Kyoto Protocol falls under the framework of the UNFCCC and builds upon its earlier treaties [Hoch et al., 2019]. The Paris Agreement set the ambitious goal of limiting global warming to well below two degrees, whilst pursuing efforts to limit the increase to 1.5 degrees. To achieve this goal, the Paris Agreement stipulates that all parties including major emitting countries shall submit and revise their GHG emission reduction target every 5 years, report their implementation status through common flexible manners as well as receive reviews. These are defined in their NDC. The Paris Agreement establishes provisions for engaging in international cooperation, including through carbon market mechanisms, to support the achievement of their NDCs.

The Katowice Climate Package, adopted in 2018 and also referred to as 'Paris Rulebook, 'further specifies that these adjustments are to be reported in a'structured summary,' including an emissions balance in which additions to NDC-covered emissions are made to account for the (first) transfer of mitigation outcomes, and subtractions are made to account for the acquisition or use of internationally transferred mitigation outcomes. The package provided the necessary details to make the Paris Agreement operational.

However, several questions were still left unanswered after the launching of the Katowice Climate package of 2018. The questions concerned issues like, under which conditions mitigation outcomes that are not covered by the scope of NDCs should be eligible for allowing international transfer and use by another country to achieve its NDC. Hence, international negotiations were held in Glasgow during COP26 to review the implementation of the convention, the Kyoto Protocol and the Paris Agreement and to adopt decisions to further develop and implement these instruments. The new rules specified after COP26 specify such rules in a way that a clear distinction in literature and empirical background should be made written before and after COP26.

Article 6 of the Paris Agreement is supposed to provide flexibility to governments in implementing their NDCs through voluntary international cooperation, which should ease the difficulty of achieving reductions targets [Poolen and Ryszka, 2021]. The underlying idea is that countries with fewer emissions would be allowed to sell their excess allowance to larger emitters, in light of an overall cap of GHG emissions. Article 6.2 and article 6.4, are targeting important accounting issues like double counting.

- Article 6.2 requires countries to *'ensure environmental integrity'* and to 'apply robust accounting to ensure, inter alia, the avoidance of double counting [Schneider et al., 2020].
- Article 6.4 creates a mechanism, under international oversight, for crediting emissions reductions that may also be transferred and used by other countries and private sector countries.

2.3.2 Cooperative Approaches, ITMO's and Art6.4ERs

Cooperative approaches are bilateral arrangements between parties in which they recognize the transfer of emission reductions between them. Hereby enabling mitigation programmes like emission trading systems in countries to link to each other. The cooperative approaches under Article 6.2 recognize that Parties to the agreement may choose to use 'internationally transferred mitigation outcomes' generated abroad to achieve their own NDCs.

As between the Cooperative Approach under Article 6.2 and the Mechanism under Article 6.4, the key differences are that under the former, government to government level arrangements have to be agreed before a Cooperative Approach can come into force. Furthermore, to participate in a Cooperative Approach, each party must meet common participation requirements (Art 6.2 Participation Requirements). The most relevant of these Art 6.2 Participation Requirements are that the country must be a party to the Paris Agreement (i.e. you cannot withdraw from the Paris Agreement but still utilise its market mechanism) and that it must have a framework in place that authorises the use of Internationally Transferred Mitigation Outcomes (ITMOs) for NDC purposes.

The authorisation framework is important in the case of both ITMOs and Art6.4ERs. How a unit should be used can, for the most part, be determined by the parties participating in the Cooperative Approach using this framework. There are three uses for which an ITMOs can be authorised:

1. for use towards an NDC (NDC Use)
2. for use towards other international purposes (International Use, e.g. CORSIA) and,
3. for use for other purposes (Other Use, e.g. voluntary corporate use) [Holman Fenwick Willian LLP, 2021]

Similar to Cooperative Approaches, a host country wishing to issue Art6.4ERs under the Mechanism, must also satisfy a similar, but not identical, set of Article 6.4 mechanism participation requirements (the Art 6.4 Participation Requirements). These include the need to establish a designated national authority (DNA) and the host country has to publicly state the types of Mechanism Activities that it would consider approving for the issuance of Art6.4ERs.

The idea is that once such Mechanism Activities are identified by the host country, public or private entities can design such activities and propose them for registration under the Mechanism. Such activities may involve reducing emissions, increasing removals and mitigation of co-benefits of adaptation actions and/or economic diversification plans. Therefore, the type of activity should not force a country to choose between approving the activity under the Mechanism or a Cooperative Approach (where it is a participant in one), since the mitigation outcome can be reflected either in the form of an Art6.4ER or an ITMOs [Holman Fenwick Willian LLP, 2021].

The Article 6.4 Guidelines do not make the Use Authorisation obligatory on the host country. This leaves the host country with discretion as to whether it wishes to benefit from the Mechanism but have the Art6.4ER used for either domestic purposes (e.g. towards a national emission trading scheme or tax regime) or whether it wishes to sell Article 6.4ERs into the voluntary markets but without having to make a corresponding adjustment. As such, it allows host countries to tap into financing opportunities in the voluntary markets or the Article 6 markets but recognising that for the latter, it will come with the additional cost of the corresponding adjustment [Holman Fenwick Willian LLP, 2021].

2.3.3 Disparities in Compliance Mechanisms

Despite the Paris Agreement being improved during every COP, several issues are apparent in the main mechanism of the Paris Agreement, the NDCs, with respect to the mitigation targets. Important issues are:

- lack of clarity of targets
- diversity in targets
- scope determination differentiation

Their is a lack of clarity in current NDCs, often the scope of mitigation targets is unclear. Some provisions directed on reporting and clarifying NDCs are only mandatory for second and subsequent NDCs or only require relevant information by 2024. The diversity of NDCs poses a problem as well as they include some form of GHG emissions targets, but parties are free to report this how they see fit. Generally defining the scope of the NDC is relatively straightforward, a country has to specify which sectors, gases, categories of emissions by sources and removals by sinks, and, for the Land Use, Land-Use Change and Forestry sector, which activities and carbon pools are covered by that target [Greenhouse Gas Management Institute and Stockholm Environment Institute, 2020]. Some NDCs, however, include only non-quantified mitigation actions or targets expressed in metrics other than GHG emissions, such as hectares of land to be afforested, or number of clean cook stoves to be distributed. The draft Article 6 negotiation texts address the issue of outside-scope emission reductions by referring to emission reductions and removals from/in sectors and GHG gasses (that are) not covered by the NDC.

Moreover, the determination whether mitigation outcomes occurred within or outside scope can be technically or methodologically difficult even if an NDC is clearly formulated to specific sectors. Firstly, mitigation measures could reduce emissions within the scope of an NDC but increase emissions outside the scope or through leakage effects [Schneider et al., 2020]. NDCs are often even more complex, as they focus on targets that are related to climate mitigation but all utilize different accounting and measuring standards. For example, an NDC can focus on renewable energy, others might focus on forestry or finance related targets. Furthermore, the target itself may be economy-wide, a subset or specific sector [Schneider et al., 2018]. In many cases the origin and corresponding project boundaries of these targets are not easily delineated from the disclosed reports.

Lastly, the issue of what a corresponding adjustment is and when it should apply for transactions that may arise under either (i) cooperative approaches under Articles 6.2-6.3 or, (ii) the sustainable development mechanism under Articles 6.4-6.7 (the Mechanism), has been one of the main sticking points preventing progress. During COP26 this was resolved by inventing corresponding adjustments, supposed to capture which entity (on a country level) can claim the transaction. However the application of corresponding adjustments proves difficult in practice and is still contested [Holman Fenwick Willian LLP, 2021].

2.4 VOLUNTARY CARBON MARKETS

Next to the compliance market, the voluntary carbon market has emerged. The market is needed to achieve the desired net-zero goal. The voluntary carbon market needs to grow by more than 15-fold by 2030 in order to support the investment required to deliver the 1.5-degree pathway [Adams et al., 2021]. A voluntary carbon credit is produced when an independent organization voluntarily reduces one ton of GHG from the atmosphere. This reduction is verified by independent third parties according to recognized standards [Reuss et al., 2022]. Companies turn to voluntary carbon markets to compensate or neutralize emissions not yet eliminated because it is either not possible or prohibitively expensive to directly reduce emissions from all activities across their value chains [Adams et al., 2021].

The voluntary carbon markets operate independently of, but in tandem with, the compliance market. The market allows institutional and retail-investors to purchase carbon credits to offset their emissions voluntarily. Independent crediting mechanisms generate the credits used for voluntary offsetting purposes and are responsible for most of the credits sold for voluntary offsetting. The credits can be produced under the CDM or other voluntary market standards [Reuss et al., 2022]. In contrast to the CDM, the voluntary market is not regulated by an international administrative body, thus voluntary standards have a particularly important role in ensuring market credibility [Blum, 2020].

Inspired by the emerging CDM rules and regulatory procedures, a number of agents initiated the establishment of four major institutions, here understood as rules and established patterns of behaviour, that now structure the VCM [Blum, 2020]:

- Voluntary standards, the rules framing the procedures and criteria for how projects should be developed and verified
- Standard-setting organizations, that is, the institutions continuously developing the voluntary standards, monitoring their application and issuing verified carbon credits.
- Third-party verification the institution establishing the independent verification of compliance with the standards
- Independent carbon credit registries, to ensure that issued carbon credits cannot be registered, claimed and hence counted several times, by transparently listing all verified projects and issued units

There are a number of standards in the market, for instance, Verra (United States), Gold Standard (Switzerland), American Carbon Registry (United States) and Climate Action/UNFCCC (United Kingdom). Their objective is to set and manage the standards for voluntary carbon credits. They oversee the guidelines and principles of carbon credit production. Furthermore, the standard specifies the accounting methodology and sets specific parameters for measuring GHG reductions [Reuss et al., 2022]. A project must have a certification from an accredited validator to become eligible for voluntary offsetting goals. The certifying entities accomplish the validation following the rules defined by the standards mentioned above.

The role played by these entities is crucial for the correct functioning of the market, similar in spirit to the role played by rating agencies in bond markets. The validators act in an oligopolistic environment with a high entry barrier [Reuss et al., 2022].

The Conference of Parties that took place in Glasgow in November 2021 (COP 26) has the potential to further boost the supply of and demand for voluntary carbon offsets, at least in some areas of the voluntary carbon offset markets. Specifically, Brazil, the country with the largest share of tropical rainforest in the world, has committed to put an end to illegal deforestation by 2030. A direct effect of this commitment could be that more voluntary carbon offset projects in forestry and land use will be conducted, which could help to further develop voluntary carbon markets [Reuss et al., 2022].

2.4.1 Overview of Offset Programs Worldwide

As previously mentioned, carbon markets can be either be mandatory or voluntary. Due to the various carbon markets, the type of carbon credit can differ but for the importance of accounting and comparability are not to be confused. Figures 2.4 gives an overview of the various offset programs.

As can be seen from the figure, Certified Emission Reductions (CER) is the name of a credit issued by the CDM under the Kyoto Protocol. Looking at the voluntary carbon credits, the Verified Carbon Units (VCU) from the Verified Carbon Standard is a robust and global standard for approval of credible carbon credits. It is currently the most widely known and one of the most often used voluntary standard and the Verified Carbon Standard is also compatible with the CDM. A major difference between the compliance and voluntary markets is that companies cannot utilize a Voluntary Emission Reduction (VER) to satisfy their responsibilities under the Kyoto Protocol's compliance framework [Reuss et al., 2022]. Another major difference between the compliance and voluntary markets is the scope of the emissions. The compliance market covers the scope 1 and 2 emissions, whereas in the European Union the voluntary market covers only scope 3 [Reuss et al., 2022].

Compliance Carbon offset programs	Geographic Coverage	Label used for offset credits	
Clean Development Mechanism	Low & middle income countries	Certified Emission Reduction	CER
California Compliance Offset Program	United States	Air Resourcers Board Offset Credit	ARBOC
Joint Implementation (JI)	High income countries	Emission Reduction Unit	ERU
Regional Greenhouse Gas Initiative (RGGI)	Northeast United States	RGGI CO2 Offset Allowance	ROA
Alberta Emission Offset Program (AEOP)	Alberta, Canada	Alberta Emissions Offset Credit	AEOC

Voluntary Carbon offset programs	Geographic Coverage	Label used for offset credits	
American Carbon Registry	United States	Emission Reduction Tonne	ERT
Climate Action Reserve (CAR)	United States	Climate Reserve Tonne	CRT
The Gold Standard	International	Verified Emission Reduction	VER
Plan Vivo	International	Plan Vivo Certificate	PVC
The Verified Carbon Standard	International	Verified Carbon Unit	VCU

Figure 2.4: Overview of Carbon Offset Programs from Broekhoff et al. [2019b]

2.5 TRANSPARENCY, TRACEABILITY AND VISIBILITY

Carbon credits are generated via carbon offsetting projects, in multi-level stakeholder environments in which many stakeholders contribute to the forming of the credit. Essentially, this generation up until the credit is sold can be seen as the supply chain. Both the concepts of transparency and traceability have been shortly touched upon and are equally important in creating the necessary visibility in the carbon markets. Optimizing transparency as well as traceability are related, and distinguishing between the two correctly is of importance for to understand the processes related to a carbon credit's generation and value chain. Francisco and Swanson [2018] gives the definition of transparency as: *"the extent to which information is readily available to both counterparties in an exchange and also to outside observers. In a supply chain context, transparency refers to information available to companies involved in a supply network. Supply chain traceability leverages transparency to operationalize organizational goals related to raw material origins and provide context to a final product or service"* (p.2). Respectively, supply chain transparency too improves accountability because actors can upload and access data and information.

Francisco and Swanson [2018] define traceability *("synonymous with 'provenance'—derived from French referring to "the origin of something") as the ability to identify and verify the components and chronology of events in all steps of a process chain."*(p.2). Traceability is hindered when material information is incomplete or missing and its merits are limited by the complexity within the supply network. Complex supply chains comprised of different actors consist of concealed elements and challenges effective and secure monitoring [Francisco and Swanson, 2018].

2.6 BLOCKCHAIN TECHNOLOGY

Blockchain is an emerging technology for decentralized and transactional data sharing across a large network of untrusted parties [Xu et al., 2017]. Blockchain technology is a distributed ledger technology. A blockchain implements a distributed ledger, able to verify and story any kind of transactions which makes the application of blockchain an interesting venture for many sectors. Applications are explored in storing electronic health records, supply chain, voting, energy supply and more [Xu et al., 2017]. By now, blockchain has become a publicly-available infrastructure for building decentralised applications, able to achieve interoperability between applications. However blockchain technology also has its limitations. A mainstream blockchain is able to handle considerably less transactions per second compared to mainstream payment services [Xu et al., 2017]. Blockchain has many configurations and internal structures which can influence such limitations. Hence, the sections below set out to discuss the main features and configurations of blockchain technology.

Simply put, blockchain can be seen as a public ledger and all committed transactions are stored in a list of blocks [Zheng et al., 2017]. The chain grows as new blocks are continuously appended to it. In a blockchain systems actors are represented and connected to the crypto-network over nodes [Mandaroux et al., 2021]. Blockchain technology generally possesses the key characteristics of decentralization, persistency, anonymity, and auditability, which allow for increasing efficiency and saving costs [Zheng et al., 2017].

Blockchain technology contains several fundamental properties. Firstly, if data is contained in a committed transaction, it will overtime become immutable. The immutability of cryptographically-signed historical transactions provides non-repudiation on the stored data. These cryptographic tools also enstate *data integrity*, public access provides *transparency*, and *equal rights* allow participants the same ability to access and manipulate the blockchain [Xu et al., 2017]. A distributed consensus mechanism regulates the addition of new items. The consensus mechanism contains rules for the validation and broadcasting of transactions and blocks, resolving conflicts. The mechanisms also ensures that all transactions are valid and that these are only added once.

The last fundamental property, *trust*, is achieved from the interactions between the nodes in the network [Xu et al., 2017]. Instead of relying on a trusted third party to facilitate transactions, the participants of the blockchain network rely on the blockchain network itself. In summary, the *immutability, data integrity, transparency, equal rights and trust* are the core properties of blockchain technology making it very attractive for differing applications.

2.7 CHARACTERISTICS OF BLOCKCHAIN

As mentioned, blockchain is a sequence of blocks, which holds a complete list of transaction records like a conventional public ledger. A block in the chain consists of the header and block body. The block header includes the following features, summarized by Zheng et al. [2017]:

1. *Block version*: indicates which set of block validation rules to follow
2. *Merkle tree root hash*: hash value of all the transactions in the block
3. *Timestamp*: current time
4. *nBits*: target threshold of a valid block hash
5. *Nonce*: a 4-byte field, usually starts with 0 and increases with every hash calculation
6. *parent block hash*: a 256-bit hash value that points to the previous block

The block body is composed of the transaction itself and a transaction counter. A block can contain a maximum number of transactions depending on the block size and the size of each transaction [Zheng et al., 2017]. The composition of a block can be found below in figure 2.5.

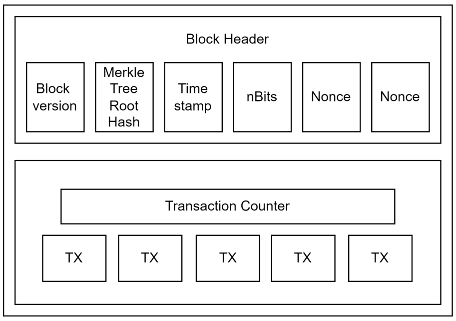

Figure 2.5: Block structure from Zheng et al. [2017]

Blockchain uses an asymmetric cryptography mechanism to validate the authentication transactions. Digital signatures based on this asymmetric cryptography are used to create trust in an untrusted environment. In order to execute a digital signature, each user must own a set of keys to validate transactions. The set consists of a public and private key. The private key should be kept confidential as it is used to sign a transaction. The digitally signed transactions are distributed throughout the whole network. The common digital signature exists of the signing phase and verification phase.

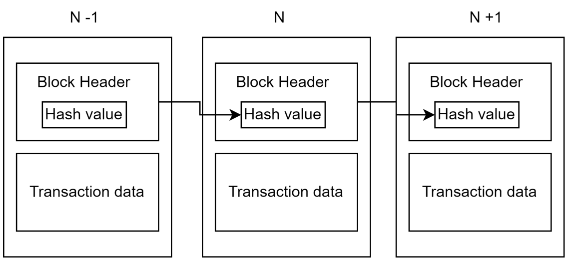

Figure 2.6: Hashing based on Zheng et al. [2017]

2.7.1 Network Topology

The blockchain network topology control point refers to the arrangements concerning who can be a node in the blockchain network and how nodes are linked. When using a blockchain, one design decision is the network typology, i.e.whether to use a public blockchain, consortium/-community blockchain or private blockchain [Xu et al., 2017]. Using a public blockchain results in better information transparency and auditability, but decreases performance and has a different cost structure. In a public blockchain the privacy relies on encryption or cryptographic hashes. A consortium blockchain is used across multiple organizations. The consensus protocol in a consortium blockchain is controlled by authorised nodes [Xu et al., 2017]. The right to read the blockchain can either be restricted to certain participants or be public to all. Private blockchain networks permission to append the blockchain is kept within one organisation. Private blockchains are most flexible for configuration since the blockchain is governed and hosted by one party.

Each network type has its own benefits and limitations, being more or less fitting related to what the blockchain tries to achieve. To sketch a clear picture of the differences between these network types, Zheng et al. [2017] made a comparison between the blockchain networks based on common properties.

- *consensus determination*. In public blockchains, each node could take part in the consensus process. For the consortium blockchain only a selected set of nodes are responsible for validating a block. In a private blockchain, the organisation itself controls the chain and can determine the final consensus.
- *Read permission*. All transactions are visible in a public blockchain, while in a consortium and private blockchain this depends on the nature of the chain.
- *Immutability*. public blockchains are near to immutable due to the large number of network participants, making it very difficult to tamper with transactions. However private blockchains are less immutable compared to a public blockchain as there are only a limited number of participants. Hence, they are more easily tempered with.
- *Efficiency*. Public chains contain a large number of nodes, increasing the time necessary for the propagation of transactions and blocks. Hence, transaction throughput is limited and latency is high. When viewer validators are part of the network, like in consortium and private chains, the blockchains could be more efficient.
- *Consensus process*. Consortium and private blockchains both maintain permission for anybody to join the consensus process, whereas in public blockchains no permission is required. Leaving it possible for anybody to join if they wish too.

A quick summary of the comparisons can be seen in table 2.1, from Zheng et al. [2017].

Table 2.1: Comparisons among blockchain networks from Zheng et al. [2017]

Property	Public blockchain	Consortium blockchain	Private blockchain
Consensus determination	All miners	Selected set of nodes	One organization
Read permission	Public	Public or restricted	Public or restricted
Immutability	Nearly impossible to tamper	Could be tampered	Could be tampered
Efficiency	Low	High	High
Centralized	No	Partial	Yes
Consensus process	Permissionless	Permissioned	Permissioned

2.7.2 Data Structures

Despite blockchain providing unique, desirable properties there are some limitations to the technology. Especially the amount of computational power and data storage space available on a blockchain network remains limited [Xu et al., 2017]. Considering cost efficiency, performance and flexibility, a design touch point identified by van Engelenburg et al. [2020] as well as Xu et al. [2017] is choosing what data and computation should be placed on-chain or off-chain. Xu et al. [2017] classifies this in (1) item data, (2) item collection and (3) computation.

- *Item data*. Storing raw data off chain, and storing meta-data, small critical data, and hashes of the data on chain is common practice for data management in blockchain-based systems. Choosing for off-chain data storage concerns the interaction between the blockchain and the off-chain data storage. The storage could either be facilitated on a client's private cloud or public storage provided by a third party or network [Xu et al., 2017]. Important to note is that, in a cloud environment data replication needs to be managed by either the system or a consumer.

  Another option could be to store data as a variable in a smart contract. Storing data as a variable in a smart contract is more efficient to manipulate, but less flexible due to the constraints of the Solidity language on the value types and length. The flexibility and performance of using smart contract log events is intermediate because log events allow up to three parameters to be queried

- *Item collection*. The notion of data item collection is common on blockchains, e.g.when using blockchain as a registry. For off-chain options, the considerations and trade-offs for item data apply apply to item collections as well.

- *Computation*. Also computations can be performed either on- or off-chain in blockchain based systems. On-chain computations are done through smart contracts. Depending on the blockchain, different levels of expressiveness for on-chain computation are provided. Hence, influencing which blockchain would be suitable related to design requirements. For example, Ethereum allow general programs which can modify working data in smart contracts, whereas bitcoin only allows simple scripts and conditions that must be satisfied to make transfers possible [Xu et al., 2017]. A clear benefit of using on-chain computation is the inherent interoperability among the systems built on the same blockchain network, as opposed to only using blockchain as the data layer [Xu et al., 2017], which is useful considering the fragmented nature of the global carbon market. Other benefits of on-chain computation are the neutrality of the execution environment and immutability of the program code once deployed [Xu et al., 2017].

2.7.3 Consensus Algorithms

In blockchain, consensus algorithms decide which nodes to trust and which nodes not to trust, leading to one true blockchain. These consensus algorithms are based on the Byzantine Generals (BG) problem [Zheng et al., 2017], in which some generals wish to attack a city while others do not. If they do not attack in full numbers the attack will fail, hence the generals have to come to an agreement. Reaching an agreement in a distributed environment proves to be difficult. Protocols for providing the steps in reaching such agreements are necessary to ensure ledgers in different nodes are consistent. A good consensus algorithm means efficiency, safety and convenience to the blockchain. Multiple approaches to reach a consensus exist and will be further explained below.

There are various commonly used consensus algorithms: Proof of Work, Proof of Stake, Practical byzantine fault tolerance, Delegated Proof of Stake, Ripple and tendermint. The next section will briefly touch upon these algorithms, specifically focused on Proof of Work, Proof of Stake and protocols since these are featured in the van Engelenburg et al. [2020] framework.

Practical Byzantine Fault Tolerance

The Practical byzantine fault tolerance is a replication to tolerate byzantine faults, like the problem of the general explained in the previous section. In blockchain terms, a byzantine fault is a condition of a computer system, particularly distributed computing systems, where components may fail and there is imperfect information on whether a component has failed. In a Byzantine fault, a component such as a server can inconsistently appear both failed and functioning to failure-detection systems, presenting different symptoms to different observers. It is difficult for the other components to declare it failed and shut it out of the network, because they need to first reach a consensus regarding which component has failed in the first place.

A Practical byzantine fault tolerance can handle up to 1/3 of malicious byzantine replicas. In each round a new block is determined, based on a set of rules and it is responsible for ordering the transaction Zheng et al. [2017]. This protocol can be divided into three phases: pre-prepared, prepared and commit. In each phase a node has to receive two thirds of the votes in order to answer the next phase. This requires all nodes to be known to the network

Proof of Work and Proof of Stake

In a decentralized network, someone has to be selected to record the transactions. Random selection however also has its downsides,since it is vulnerable to attacks. Meaning that when a node wants to publish a block of transactions, a lot of work has to be done to prove that the node is unlikely to attack the network (the work commonly being computer computations) Zheng et al. [2017]. In a Proof of Work consensus strategy, each node in the network is calculating the hash value of the header. Nodes that calculate the hash value are called *miners* and the Proof of Work procedure is called *mining*.

It is possible for valid blocks to be generated simultaneously in a decentralized network when nodes find the suitable nonce approximately at the same. This might result into forking, in which branches of the chain are generated. It is unlikely however that these forks continue generating new blocks simultaneously. The Proof of Work protocol than selects the longest chain as authentic. In Proof of Work miners have to do a lot of calculations, making intensive use of resources.

Proof of Stake is similar to Proof of Work but saves energy. Miners in a Proof of Stake have to prove the ownership of the amount of currency. It is believed that people with more currencies would be less likely to attack the network according to Zheng et al. [2017]. It is however unfair to base the protocol on solely account balance, since the richest are bound to become dominant in the network. Hence, solutions were designed with the combination of stake size to decide which node may forge the new block.

2.7.4 Visualization Blockchain Structure

The layers of blockchain play a significant role in the design of a blockchain architecture, since each layer filters out unnecessary information and lighters node traffic. Different studies maintain different layers but in general the *application layer, Consensus layer, network layer, data layer and hardware layer are discussed.* Figure 2.7 depicts the classical five-layer DLT structure. The model is a graphical representation of the components of DLTs, most of which have been discussed in section 2.7. The data layer can be structured as a public (permissioned), private (permissionless) or consortium (hybrid) chain. The network layer represents the internode communication, which ensures that nodes can discover each other and can communicate, propagate and synchronize to maintain a valid current state of the blockchain network [Acharya et al., 2019]. The consensus layer handles the ordering and validation of the block, based on a specific consensus mechanism. The top layer represents the user interfaces and end-user applications [Mandaroux et al., 2021].

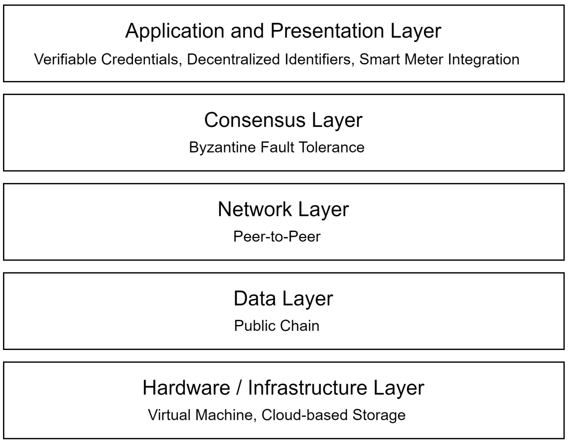

Figure 2.7: Classical layers of Distributed Ledger Technology

2.7.5 Smart Contracts

An attractive feature of blockchain technology is smart contracts. A smart contract is executable code that runs on the blockchain to facilitate, execute and enforce the terms of an agreement between untrusted parties. The contract contains rules based on which digital assets are released to allocated parties, once the pre-defined rules have been met. Smart contracts therefore do not rely on trusted third-parties to ratify the contract. The main aim of smart contracts is to automatically execute the agreement once the pre-defined rules have been met. Smart contracts consisting of transactions are stored, replicated and updated in distributed blockchains.

Overall smart contracts have three main advantages, namely risk reduction, reduction of administration and service costs and improving efficiency of business processes [Zheng et al., 2020]. Risk is reduced due to the immutability of blockchains, the smart contracts cannot be arbitrarily altered once they are issued and they are stored and duplicated throughout the blockchain system, making them traceable and auditable. This reduces the risks of financial frauds for example. As explained in section 2.7.2, blockchains assure the trust of the system through consensus mechanisms making a third party validator redundant. In the blockchain system smart contracts can be automatically triggered in a decentralized way. Lastly, the elimination of the dependence on the intermediary can significantly improve business process efficiency [Zheng et al., 2020]. Due to the automatic nature of smart contracts the turnaround time for a transaction can be significantly reduced.

Despite smart contracts being a major innovation in blockchain technology, every application also has its challenges. Remaining challenges for smart contracts are identified in the programming language, security and privacy issues and unintentionally, or mischievously generated bugs [Zheng et al., 2020].

2.7.6 Tokenization

Apart from the blockchain technology itself, e.g.functioning as registry in the carbon market, the carbon credits, need to be tokenized in order to be traded on the blockchain. According to Xuefeng, Li and Wu, X and Pei, X and Yao, Z [2019] tokens are digital rights, that represent for utilities, asset and security. Tokenization is generally the process of representing a given (financial) asset as a unit on the distributed ledger, a representation maintained by the individual nodes running versions of the blockchain client software [Ross et al., 2019]. By representing a given asset as a *transferable unit of account* on the blockchain, counter parties can leverage the technical features of the underlying technology to reduce both cost and settlement time, while mitigating risks traditionally associated with the transfer of ownership of financial assets.

From a finance property aspect of view, Xuefeng, Li and Wu, X and Pei, X and Yao, Z [2019] define the tokens and coins generated by the blockchain are both regarded as cryptocurrency, which is a kind of encrypted digital or virtual currency. Cryptocurrencies use cryptographic algorithms to secure and verify all the transactions. Coins are the native currency of blockchains, derived from Bitcoin. Other coins apart from blockchain are nowadays too considered as cryptocurrency coins. On the contrary, tokens are always on top of the blockchain through the use of smart contracts. As mentioned tokens can represent different rights, here we focus on asset-backed tokens since they present real world assets. The assets represented could be real estate, art, derivatives markets, non-fungible assets, commodities and even identity. The next paragraph will dive further into non-fungible assets.

Non-Fungible Token (NFT) is a type of cryptocurrency based on the smart contracts of Ethereum [Wang et al., 2021]. NFT differs from traditional cryptocurrencies like Bitcoin in their intrinsic features. These traditional currencies are indistinguishable and each coin is equivalent to the other. NFT on the other hand is uniquely identifiable, making it suitable for identifying an asset in a unique way. Wang et al. [2021] explains that by using NFTs on a smart contract, *"a creator can easily prove the existence and ownership of digital assets in the form of videos, images, arts, event tickets, etc."* NFTs allow for full-history tradability, deep liquidity, and convenient interoperability, which enabled them to become a promising intellectual property protection solution.

The first step in tokenizing an asset given by Sazandrishvili [2020] is *asset identification*, with the precondition that the asset should be fully defined and the nature and amount of asset you want to trade on a blockchain should be completely described. After *asset identification* and step two, *asset evaluation* have been completed, we arrive at the step of *tokenomics* where token parameters must be determined in order to create the digital token [Sazandrishvili, 2020]. Decisions such as how many tokens will be issued, whether and how new tokens will be added and what happens to lost tokens have to be made. Sazandrishvili [2020] claims this to be the most difficult step of tokenizing assets and many projects fail at this stage.

The significance of NFTs is that they bring scarcity into the digital realm, enabling the ownership and trading of assets in a digitalized environment [Valeonti et al., 2021]. Considering the construct of ownership, when one buys an NFT, the transaction is registered on the blockchain and from thereon no one can question, challenge, obfuscate, or compromise one's ownership of a given asset. Despite NFTs are very promising, the technology is still in its early stages and potential challenges need to be addressed [Valeonti et al., 2021]. One of the drawbacks of NFTs is that their ecosystems are isolated from each-other. Once one type of product has been selected it can only be sold, bought or traded within the same ecosystem or network [Wang et al., 2021]. This is due to the underlying blockchain platform. However most NFT-related projects adopt Ethereum as their underlying platform which indicates that they share a similar data structure and could exchange under the same rules [Wang et al., 2021].

Another main risk associated with NFT is the same risk applicable to any other token or cryptocurrency, related to the security of crypto wallets and their cryptographic keys that allow their owners to access them [Valeonti et al., 2021]. Two often adopted practices are either custodian models, in which the NFT platforms manage such keys on behalf of their users or crypto wallets in which users can store their NFTs and can manage themselves. Custodial wallets are simple to set up and easy to use, accommodated with features such as password recovery and account retrieval [Valeonti et al., 2021]. The downside of custodian models is that users do not have true ownership of their NFTs, as they are not stored in their own wallets on the blockchain. The risk arises that the network hosting the NFTs is compromised, or declared bankrupt and solvency issues could arise. Users storing their own NFTs however also face risks of compromised NFTs. If they lose access to their wallet or somehow lose their cryptographic keys for the wallet, access to the contents of their wallet is immediately lost [Valeonti et al., 2021].

3 RESEARCH METHODOLOGY

This chapter presents the selected research approach for the master thesis. The chapter starts with the explanation of the research method in Section 3.1. A single case study was chosen to answer the main research question. The choice to follow a single case study approach was twofold. Firstly, the collaboration with Acorn presented unusual research access to an project developer in the VCM and the approach advocates that a specific case can be used to obtain a larger understanding of an issue or phenomenon. Secondly, employing case study research as a research strategy can be used to develop theory. The theory to be developed is the framework supposed to evaluate the benefits and limitations of blockchain-based platforms.

Next, the chapter discusses the framework selected to focus the case study research in Section 3.2. A theoretical framework was necessary to situate the researcher in a scholarly conversation, determine what data needed to be collected and facilitate data interpretation. Academic literature on blockchain evaluation frameworks was sought to guide the thesis. The theoretical framework of van Engelenburg et al. [2020] was the sole framework adopting a socio-technical systems view on blockchain-based platforms, to assess the alignment between stakeholders interest and blockchain design choices. Therefore, the framework was was used throughout the research. Related to the framework, blockchain-based systems are viewed as *"complex socio-technical systems in which many stakeholders with divergent interests are involved."* by van Engelenburg et al. [2020]. This view is followed throughout the research. Section 3.2 further explicates the framework of van Engelenburg et al. [2020], by elaborating on the stakeholder view, governance requirements and blockchain control view of the framework.

Section 3.3 elaborates on the context of Acorn and the main unit of analysis in the case study. Acorn – Agroforestry CRUs for the Organic Restoration of Nature – is a program being developed by Rabobank to unlock the international carbon market for smallholder farmers in the developing world. The main unit of analysis is the blockchain solution developed by Acorn two years ago. Acorn researched if it was feasible to adopt blockchain technology for their marketplace, but decided the market and the technology itself was not ready.

This is followed by the data collection techniques in Section 3.4. The main research methods employed were desk research, case study method, and interviews. For the case study, apart from the theoretical sampling at the start of the research, seven interviews were conducted. Five interviews were held with Acorn experts, the other two interviews were held with technology providers. One workshop was held with the strategy lead of Acorn to brainstorm about the preliminary results. In total, four webinars were attended and numerous articles, rapports and websites were consulted. The case study protocol that guided the data collection process can be found in Appendix B.1.

The chapter concludes with the description of the data analysis in Section 3.5. The computer-assisted qualitative data analysis software Atlas.ti was used to code and categorize the data. Lastly, Section 3.5 elaborates on the development of the framework and how theory building was used to identify new concepts.

3.1 RESEARCH APPROACH

The research approach is both interpretative and instrumental as it aims to understand and describe the issue of double counting for Acorn, the possibilities for blockchain-based applications to prevent double-counting as well as extend the findings to the bigger context [Walsham, 1993; Crowe et al., 2011]. Eisenhardt and Graebner [2007] advocate that building theory from case studies is a research strategy that involves using one or more cases to create theoretical constructs, propositions and/or mid-range theory from case-based, empirical evidence. As a research strategy, the case study is used in many situations, to contribute to our knowledge of individual, group, organizational, social, political, and related phenomena. A case study provides the opportunity to shed empirical light about some theoretical concepts or principles [Crowe et al., 2011; Mills et al., 2009].

Considering the objective of the research, to develop a framework that can evaluate the benefits and limitations of blockchain-based platforms to prevent double counting in the voluntary carbon market case study is most fitting Crowe et al. [2011]; Eisenhardt [1989]; Eisenhardt and Graebner [2007]; Walsham [1993]. It allows for the in-depth analysis of the interrelations, governance and stakeholders through the lens of van Engelenburg et al. [2020] framework and the consecutive development of the MLGBE framework. In an instrumental case study, a specific case is used to obtain a larger understanding of an issue or phenomenon [Mills et al., 2009]. This larger context is provided by the global market which has great influence on any solution proposed due to the existing interrelations. The research is exploratory by nature since the problem of double counting and its varying causes have not been clearly defined yet and in which no singular, final solution is presented to solve the problem [Mandaroux et al., 2021].

The single case is selected since it presented the opportunity of unusual research access [Eisenhardt and Graebner, 2007]. Moreover, a single-case study can represent a significant contribution to knowledge and theory building by confirming, challenging, or extending the theory [Yin, 2018]. Eisenhardt and Graebner [2007] also argues that single case studies can enable more complex theories to emerge compared to multiple-cases since-case theories can cover the relationships of a particular case in more detail. The theory building starts with the in-depth analysis of Acorn. The collaboration with Acorn provides access to rich data. From the data analysis new concepts and relations are identified, these can then be translated into the framework. Together these steps generate new theory and the new theory is represented in the developed framework [Mills et al., 2009; Eisenhardt and Graebner, 2007].

The stages of the Case Study defined by Crowe et al. [2011] are: (1) defining the case; (2) selecting the case(s); (3) collecting the data; (4) analysing, interpreting and reporting the findings. These stages will be adopted to frame the research and structure the sub questions. Important to note is that the research aims to both identify the benefits and limitations of blockchain technology, as well as extend or adapt the conceptual model that is adopted to guide the case study. This asks for an iterative approach in which the developed theories are deeply informed by the empirical context [Eisenhardt and Graebner, 2007]. It requires cycling among the case data, emerging theory and extant literature [Eisenhardt and Graebner, 2007]. Hence, the phases adopted to structure the research approach are not seen as rigid and become blurred as the research progresses.

As voluntary carbon offsetting is an undoubtedly new and complex market, a theoretical framework is necessary to situate the researcher in a scholarly conversation, determine what data needed to be collected and facilitate data interpretation. Academic literature on blockchain evaluation frameworks was sought to guide the thesis. The theoretical framework of van Engelenburg et al. [2020] was the sole framework adopting a socio-technical systems view on blockchain-based platforms, to assess the alignment between stakeholders interest and blockchain design choices. Therefore, this framework is used throughout the research.

Additionally, carefully formulated research question(s), informed by the existing literature and a prior appreciation of the theoretical issues and setting(s), are all important in appropriately and succinctly defining the case [Crowe et al., 2011]. This is where the framework of [van Engelenburg et al., 2020] too guides the thesis. When conducting an instrumental case study, staying close to the questions or foreshadowed issues is necessary to be sure that the gathered data will illuminate the central focus of the study Crowe et al. [2011]. Opting to start with a theoretical framework provides a basis that helps to formulate the right questions and identify relevant issues. The risk of using a framework can be that it might constrain the study to only those questions/issues that fit the framework [Leavy, 2014, p. 461].

To address the risks of theory development like selective bias or drifting, frequent checks with the original purpose of the inquiry will be embedded through discussions with the problem owner and external researchers. A final step to guard the research rigor, will be the implementation of a formal review process in which the informants of the case study review the findings Crowe et al. [2011]. The corrections made through this process will enhance the accuracy of the case study, hence increasing the construct validity of the study. As to not extend the completion of the report, this reviewing should be done in a timely manner.

Lastly, addressing the limitations of the chosen research approach, a general concern of case studies to consider is the lack of scientific rigor and providing little basis for generalization [Crowe et al., 2011]. This concern is addressed through theoretical sampling, as well as respondent validation by presenting the findings to the involved experts. Theoretical sampling is done through the application of the van Engelenburg et al. [2020] framework. Another limitation of case studies can be the lack of analytical depth due to limited the volume of data, together with time restrictions in place. These concerns will be further addressed in section 2.7.2. The next sections of the chapter will discuss, (1) the theoretical framework (2) the empirical context of the case; (3) the data collection and corresponding methods; (4) data analysis; and (5) the MLGBE framework development.

3.2 FRAMEWORK FOR COMPLEX SOCIO-TECHNICAL SYSTEMS

In order to develop the MLGBE framework, the current body of frameworks that facilitate the evaluation of blockchain solutions had to be evaluated first. The extant literature showed that the framework of van Engelenburg et al. [2020] was the most suitable framework to guide the research. In the beginning of the research, the framework directed the researcher towards areas of interest. Starting with the stakeholder context and technical domain of the VCM. Carefully formulated research question(s), informed by the existing literature and a prior appreciation of the theoretical issues and setting(s), are all important in appropriately and succinctly defining the case [Crowe et al., 2011]. During the data collection the framework helped to categorize relevant questions under stakeholder dynamics, governance requirements and blockchain design points. In the analysis, the propositions in the framework, guided the systematic evaluation of the case at hand. To understand how the framework served the research, the framework is discussed more in detail in the subsequent paragraphs.

To start with, van Engelenburg et al. [2020] considers blockchain based systems to be *" complex socio-technical systems in which many stakeholders with divergent interests are involved."* This definition is inherent to carbon markets. van Engelenburg et al. [2020] proposed a framework for systematically analyzing the relationship between governance in business & governance information sharing and design choices in blockchain technology. The framework illustrates the difficulty of systematically translating high-level dynamics between stakeholders into blockchain design choices, and vice versa. The framework itself is comprised of three components: *the stakeholder view, the governance requirements* and *the blockchain control points*. The governance requirements link both the stakeholder view and the blockchain control points to allow for the translation of stakeholder dynamics into specific blockchain configurations.

Before the framework can be applied in the case study protocol a deeper understanding of its components is required. Hence, the following paragraphs will discuss the stakeholder view, governance requirements and blockchain control points in detail.

3.2.1 Stakeholder View

First, the right side of the framework will be examined. The stakeholder view of the van Engelenburg et al. [2020] framework is used to map the actors, their responsibilities and dependencies (See Figure 3.1).

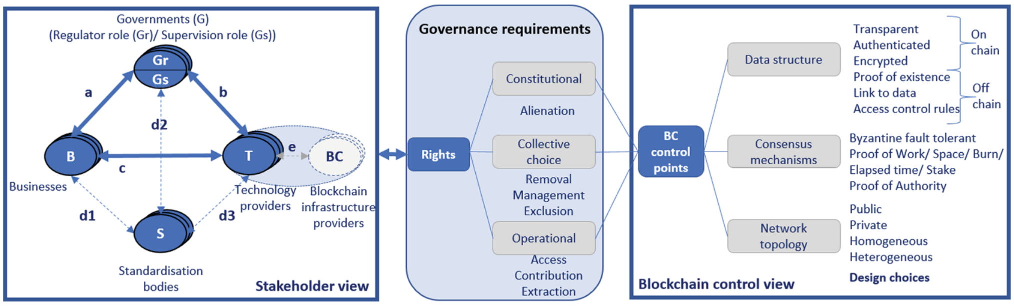

Figure 3.1: Stakeholder view from van Engelenburg et al. [2020]

van Engelenburg et al. [2020] argues that to develop blockchain-based systems, the complexities and specificity's of the business & governance domain are key for understanding the design options. She discerned the following four stakeholder categories to guide the analysis in this domain:

- Businesses (B),
- Government agencies (G),
- Technology providers (T),
- Standardization bodies (S)

For businesses the motivation to implement blockchain technology generally comes from the need of competitive advantage, or social corporate responsibility. The government agencies can act in different roles, either as regulator or as supervisory body for business activities. The technology providers refer to infrastructure and platform providers and lastly the standardization bodies play a role in organizing interoperability of blockchain-based systems and services. The solid arrows depict primary links and the dotted arrows illustrate secondary links. All of the links in the model can be used to identify potential tensions. The aforementioned categories are adopted in the case study to categorize the wider context of the global carbon markets and Acorn's specific context.

3.2.2 Governance Requirements

The novelty that the van Engelenburg et al. [2020] framework brings is that is one of the first frameworks connecting high-level stakeholder dynamics to hands-on low level design choices for the blockchain architecture. The connecting between these two aspects on opposite ends of the spectrum is made via so-called governance requirements. As van Engelenburg et al. [2020] explains, governance requirements are a description of to what extend certain parties should have specific rights with respect to the blockchain. The governance requirements defined in the framework are based on the work of Constantinides [2012]. He views the infrastructure resources of a blockchain as similar to analogous natural resources, and based on this viewpoint three types of rights are distinguished: *constitutional*, *collective choice* and *operational rights*.

Constitutional rights concern the rights of whom can participate in collective choice making for the system. Collective choice rights cover the rights concerning users and components within the information system. Lastly, the operational rights refer to those related to access to the information system and its corresponding data. van Engelenburg et al. [2020] created an overview, see table 3.1, of the differing rights in the context of blockchain-based business & governance information sharing systems.

Table 3.1: Different types of rights in blockchain-based B&G information sharing systems adopted from van Engelenburg et al. [2020]

Rights	**Rights in a blockchain-based system for B&G information sharing**	
Constitutional rights	Alienation	Right to determine who has what collective rights
Collective choice rights	Removal	Right to remove parts of the blockchain-based system
	Management	Right to determine how, when and where parts of the blockchain-based system can be used and choices on control points may be changed
	Exclusion	Right to determine who has what operational and removal rights and how these can be transferred.
Operational rights	Access	Right to access parts of the blockchain-based system
	Contribution	Right to store, revise or delete data shared using blockchain
	Extraction	Right to access to data shared using blockchain

As van Engelenburg et al. [2020] argues, the business & governance sharing domain is complex in nature, due to the multiple stakeholders with diverging interests, parties often need to share rights. Exploring how these rights were initially allocated in Acorn's blockchain solution, allows for more insight into design choices made and can simultaneously help to devise how the rights should be allocated in light of double counting and what effects this would have on both the blockchain solution and stakeholder dynamics.

3.2.3 Blockchain Control View

As mentioned in Chapter 1 blockchain distributed ledger technology could pose as a solution for double counting through a decentralized repository of data allowing secure transactions between untrusted parties with algorithmic-based consensus. The framework of van Engelenburg et al. [2020] depicts the units of study to consider and will guide the process of evaluating blockchain-based systems.

Looking at table 3.2, a distinction is made between control points, used to control who can exercise what rights, and design choices for said control points. The framework distinguishes three categories of control points, namely: *data structure, consensus mechanisms and network typology* and related design choices. As mentioned, the blockchain control view connects design choices and governance requirements for the blockchain-based system. The design choices portray the various identified design options for the control points.

Table 3.2: Overview of control points and design choices in the framework [van Engelenburg et al., 2020]

Control Point	Design Choice	Description
Data Structure	Transparent	The data to be shared is stored on the blockchain without encryption.
	Authenticated	The data to be shared is stored on the blockchain. The party that adds the data encrypts it to authenticate it. Others can decrypt and verify their identity.
	Encrypted	The data to be shared is stored on the blockchain. The party that adds the data encrypts it to keep it confidential from others. Only parties provided with a key can view the data.
	Proof of Existence	A hash of the data to be shared is stored on the blockchain to prove it existed when it was added and make it possible to determine whether the data changed afterwards. The data itself is stored elsewhere.
	Link to data	A link to the data to be shared is stored on the blockchain. The link can be used to find the data stored elsewhere.
	Access control rules	Rules for controlling access to the data that needs to be shared is stored on the blockchain. Parties are allowed to extract the data stored elsewhere based on these rules.
Blockchain network topology	Public	Anyone can be a node in the network.
	Private	Only some parties can be a node in the network and have certain rights.
	Homogeneous	All nodes store the same data and link in the same way to other nodes.
	Heterogenous	Nodes differ in the data that they store and/or the links they have to other nodes.
Consensus mechanism	Byzantine fault-tolerant	Relies on 'good' nodes not forwarding malicious messages to the rest of the network. Requires the network not to be public to avoid Sybil attacks.
	Proof of work/ space/stake ...	Relies on nodes performing a certain task or having a certain property and the rest of the network checking this before accepting the blocks they add.
	Proof of Authority	Only authorized nodes control who can add blocks to the blockchain.

In sections 2.7.1, 2.7.2 and 2.7.3 we touched upon the three control points in the context of understanding blockchain technology. Now the influence of the control points on who can exercise what rights in the system are discussed. The data structure refers to data being stored either on- or off-chain. Here, an important effect of the choice of encrypting data is that someone with extraction rights requires a key to be able to exercise their rights [van Engelenburg et al., 2020]. The network typology determines the arrangements concerning who can be a node in the network and how nodes are linked. The consensus mechanism affects rights in two ways. Firstly, the consensus mechanism of a blockchain determines how a consensus between parties is reached regarding what blocks should be in the chain, who is allowed to add these blocks and under which conditions. The choice of consensus mechanism therefore directly affects contribution rights in the network. Furthermore, the consensus mechanisms too determines who can decide which parties should be able to exercise contribution rights.

3.3 CASE STUDY CONTEXT

The study is almost entirely based on the in-depth analysis of Acorn. Getting sufficient access to acknowledged parties in the VCM is difficult. This difficulty was increased by the technical requirements of the research scope. The empirical context for the case study was provided by Acorn from Rabobank.

Acorn was kind enough to provide detailed information on their processes, governance and in-house research on blockchain-based applications. Via Acorn additional access to several technology providers operating in the VCM was gained. The perspectives from these technology providers helped to assess market developments and analyse blockchain-based applications for the VCM from another perspective. The case was selected based on convenience and theoretical sampling, as a unique opportunity presented itself to study a VCM project developer and market enabler in-depth [Eisenhardt and Graebner, 2007]. Through EY, the connection with Rabobank was made and without their network it would have been difficult to gain as rich access.

Acorn – Agroforestry CRUs for the Organic Restoration of Nature – is a program being developed by Rabobank to unlock the international carbon market for smallholder farmers in the developing world [Rabobank Acorn, 2021]. Rabobank founded Acorn due to their history of supporting farmers with agriculture, the pressing climate needs and the opportunity of a valuable business plan. Rabobank had a desire to help small farmers to become more resilient to climate change. The first and final idea was to funnel earnings towards smallholder farmers through the mechanisms of the voluntary carbon market. Within Acorn, they specifically aimed to design a method for the robust and valid measuring of carbon sequestration in trees, which they have succeeded in by employing remote sensing.

Hence, Rabobank introduced a scalable agroforestry and carbon sequestration monitoring system. CRUs are developed based on carbon stored in planted trees. An Acorn CRU is only sold after trees have converted carbon into biomass. This process is measured on a smallholder farmer's land with the help of remote sensing technology, such as satellite imagery. Rabobank is developing Acorn into a fully traceable, ex-post solution. Ensuring that a good method is in place, providing ex-post carbon removal units ensures a high quality standard of the credits, in which Acorn wants to set an example and shape the voluntary carbon market where possible.

A crucial aspect for Acorn is to provide quality and credibility of the CRUs. By collaborating with accredited parties like Plan Vivo (an Offset Project Standard for forestry, agricultural, and other land-use projects with a focus on promoting sustainable development), agroforestry scientists and experts, a sounding board was created to support Acorn's proposition by sharing comprehensive market knowledge and advice. Acorn's Framework consists of guiding principles, in which one is specifically focused on double counting [Rabobank, 2021]:

"Principle 7: All Acorn CRUs are traceable, uniquely registered and accounted for.

4.7.1 In order to prevent double counting, issuance, use or claim of project emissions reductions, all CRUs shall be registered in a public register with a unique serial number, highlighting when (year), where (country, GPS coordinates) and by whom (local partner) the CRUs were generated."

3.4 DATA COLLECTION

A case study requires the collection of multiple sources of evidence [Crowe et al., 2011]. Moreover, Yin [2018] advocates that developing convergent evidence, data triangulation helps to strengthen the construct validity of your case study. The multiple sources of evidence essentially provide multiple measures of the same phenomenon. Hence, varying sources like documents, observations and expert interviews were drawn upon throughout the data collection to increase the research validity [Crowe et al., 2011]. There is however the risk of implementing to many data collection techniques [Yin, 2018], this is tackled by early on understanding of open-ended interviews and creation of an annotated bibliography of selected documents. Moreover, to increase the reliability of the information in a case study a chain of evidence is maintained (See Appendix B). Altogether, this research employed three data collection methods: (1) desk research, (2) semi-structured interviews and (3) a case study.

For the data collection and data analysis an iterative process was applied, as an iterative approach allows for development of theories that are deeply informed by the empirical context Eisenhardt [1989]. The process of data collection started with preliminary data collection, followed by the interpretation of findings, identification of differences and further iterations to reconcile differences. The data collection was guided by the dimensions of van Engelenburg et al. [2020] framework. The framework served as motivation to map the market mechanisms of the carbon market. In order to adequately address the complexity of the issue of double counting, the problem domain had to be dissected before the frames of the framework can be applied. Using the middle box of the framework supported the formation of the requirements with respect to governance requirements regarding blockchains aimed at solving double counting. To do so, a descriptive chapter on the foundations blockchain technology related to the carbon market was written. When the delineation of the problem domain was completed and initial data was collected, the framework was used to guide the case study protocol by discerning the units of analyses for the case study.

The data collection was performed as follows: bi-weekly, face-to-face calls, with the strategy lead of Acorn from the beginning of the research until completion. Besides, a total of seven semi-structured, open-ended interviews were conducted. Apart from the sessions with the strategy lead, five interviews were held with Acorn employees on the management decisions surrounding blockchain and Acorn, the technical considerations and the functional requirements of the intended blockchain registry. Inquiries about their vision on tokenization for the carbon market and future market developments were also made. Two interviews were held with technology providers who tokenized carbon credits on their blockchain platforms. The focus of these interviews was directed towards employing blockchain, and more specifically the functionality of tokenization and its feasibility to prevent double counting. Their position in the market and their considerations for entering the VCM, as well as their view on market developments were too investigated. An overview of the information sources and how many corresponding accounts have taken place is provided in Table B.1 in Appendix B.

During the various stages of data collection, detailed meeting notes were taken, and the demarcation of the problem (including conceptual models visualizing the findings) were sent back to the Acorn's experts for comments and further clarification. This allowed for identifying inaccuracies in the interpretations and their correction before building upon them further during the data analysis. The following sections discuss the methods employed during the data collection.

3.4.1 Desk Research

An important part of the desk research is the literature review. The literature review builds upon the knowledge base presented in Chapter 2, and extends on the issues experienced in the carbon market related to double counting. The strategies used for desk research were backward snowballing of key articles that were already identified in the preliminary literature review as well as researching the influential concepts via multiple search engines (i.e.Scopus, Google Scholar & Google) [Jalali and Wohlin, 2012]. A distinction is made between types of secondary data. The first type contains articles based on scientific research. Characteristics to gauge rigor like peer-reviews, and journal quality are considered in the search. The other type of data consists of reports, newsletter articles or company websites since many evaluations and discussions on the VCM are presented in these formats.

3.4.2 Case Study Method

The case itself is already discussed in section 3.3. To elicit the desired information during the case study, Yin [2018] defined several steps. He recommends to clearly establish the unit of analysis, develop case study propositions and complementary questions that should be answered through performing the case study. Case study propositions direct attention to something that should by examined within the scope of study [Yin, 2018].

Moreover, asking the right questions is essential to the success of a case study [Mills et al., 2009]. Hence, the thesis formulated several propositions and case study questions to guide the case study in Appendix B.

3.4.3 Interviews

Interviews are one of the most important sources of case study evidence [Yin, 2018]. For this research semi-structured, open-ended interviews were conducted since they are very well suited to research uncharted territory with unknown but momentous issues as well as to evaluate formative programs and desire access to key individuals [Newcomer et al., 2015]. The interviews resembled guided conversations and are fluid, often referred to as 'in-depth interview' or 'semi-structured interviews'. The interviews were conducted using interview protocols (Appendix A) comprised of predetermined primary questions or question stems [McIntosh and Morse, 2015]. McIntosh and Morse [2015] further note the importance of the questions being open-ended to elicit unstructured responses and generate discussions.

Turner [2010] advocates the strength of using a general interview guide approach as well, as it supports the researcher in ensuring that the same general areas of information are collected from each interviewee. This provides more focus than the conversational approach, but still allows a degree of freedom and adaptability when extracting information from interviewees [Turner, 2010]. One potential pitfall to consider during the data collection specifically when using interviews, is the collection of too large volumes of data that are not relevant to the case. Hence, the interviews to gain empirical context were structured and limited in time.

The interviewees were selected based on their knowledge of both the carbon markets as well as blockchain technology. Multiple Acorn employees were selected to capture differing views on the technology and outlook on market developments. Experts part of technology providers were sought out to gain knowledge on how they shaped the tokenization of carbon credits, what considerations and requirements arose in this process, technology restrictions and their outlook on carbon markets. By interviewing technology experts from different organizations, strategy differences could also be discovered. Combining the answers from these stakeholder groups facilitated in the answering of sub-question 3, 4 and 5.

Table 3.3 provides an overview of the semi-structured interviews used for the case study itself, the interviews held as part of the theoretical sampling are not included in this table.

Table 3.3: Overview of Interviews part of data analysis

Overview of Interviewee's Case Study	
Acorn Employees	1. Strategy Lead
	2. Blockchain Expert
	3. Blockchain Expert
	4. Founder
Technology Providers	5. Project Expert Toucan
	6. Blockchain Expert Quantoaz

3.5 DATA ANALYSIS & INTERPRETATION

The analysis of the data was also performed in an iterative manner. Repeated reviewing and sorting of voluminous and detail-rich data are integral to the analysis process [Crowe et al., 2011; Eisenhardt and Graebner, 2007]. New data sources continuously came forward, which required several iterations of the coding applied for the data analysis. For the data analysis the data needed to be organized and coded to allow key issues to be easily retrieved at a later stage.

Essentially, the coding of data facilitates the research process to analyze the data in a structured manner. In order to maximize the correct and fast proceedings of the data analysis, an initial frame of general concepts and themes was established to guide the coding process [Leavy, 2014]. The propositions in the framework of van Engelenburg et al. [2020] were built upon to form the coding framework used for the analysis (Appendix B.3).

Accordingly, the blockchain control points in the framework were used to evaluate the design decisions of the blockchain solution of Acorn and to assess to what extent the solution adheres to the requirements.

3.6 THEORY DEVELOPMENT: MLGBE FRAMEWORK

An essential feature of theory building is comparison of the emergent concepts, theory, or hypotheses with the extant literature. This involves asking what is this similar to, what does it contradict, and why. A key to this process is to consider a broad range of literature tying the emergent theory to existing literature enhances the internal validity, generalizability, and theoretical level of theory building from case study research [Eisenhardt, 1989].

The MLGBE framework was developed during the final stages of the research. Throughout the research, a newfound understanding of the van Engelenburg et al. [2020] framework was acquired. Meanwhile, concepts of the case study that did not fit into the current views of framework emerged. By integrating these concepts and the framework of van Engelenburg et al. [2020] initial versions of the MLGBE framework were developed. However, these did not capture the dynamics found between the technology and governance requirements fully. Hence, additional theory on multi-level governance and stakeholder dynamics was searched to convey these dynamics. Also literature on market legitimacy and quality was explored to assure grounded depiction of the concepts that emerged from the case study. By doing so, the first iterations to the MLGBE framework were made

4 SOCIAL DIMENSION

This chapter captures the social dimension of double counting in the VCM. The framework of van Engelenburg et al. [2020] is divided into three views, *(1) the stakeholder view, (2) governance requirements and (3) blockchain control view*. To understand how blockchain could prevent double counting these views have to be made explicit. This facilities the integration of stakeholder dynamics and technical opportunities. The analysis starts with the stakeholder view, to make insightful how the stakeholder dynamics affect double counting. Thereby, this chapter answers sub-question 1: *"What is the problem of double counting taking on both a broader stakeholder and Acorn specific perspective?"*

The problem demarcation begins with the overarching issues experienced in the VCM, to demonstrate how double counting adds to market instability in the VCM. Legitimacy and trust are identified as the crucial values that need to be met in order for the VCM to function. Moving one level below, legitimacy and trust are based upon project quality of carbon offset projects, transparency in these projects and global accounting standards. This is followed by the explication of double counting based on extant literature, extended by empirical observations in Section 4.3. Double counting can be classified in four categories: double issuance, double claiming, double selling, double purpose. Double issuance and double claiming were identified as the most difficult as well as important to solve.

A simplified visualisation of double counting (Figure X) has been made to make it easier to understand the problem at hand in Section 4.4. The analysis showed that empirically, double claiming is happening in three forms: (1) between voluntary projects and NDCs, (2) between supply chains and voluntary projects and (3) between NDCs and supply chains. The main parties involved here are national governments, project developers who operate on global levels and lastly companies that disclose on their sustainability performance. What becomes clear is that double counting cannot be solved by just one or two actors in the stakeholder field.

To deepen the analysis of the stakeholder dynamics a formal chart (Figure 4.2) is created in Section 4.2. The formal chart maps the relations and actors involved, which helps to identify stakeholder dependencies and collaborative initiatives in the VCM. After the formal chart was made, the stakeholders were grouped into categories based on the frameworks categories of van Engelenburg et al. [2020]. Five categories were made namely, government agencies, businesses, technology providers, standardisation bodies and NGOs. The category of NGOs was not yet captured in the framework of van Engelenburg et al. [2020].

In the last Sections the case of Acorn is described. Section 4.5 further explicates the case through the creation of a value model (Figure 4.6), which helps to delineate the nature of relations between Acorn and its direct stakeholders. The main takeaway is that due to the global and intangible nature of a carbon credit, the creation process of a CRU is similar to a diverging and converging funnel, progressing from a local to global stage. Another key notion is that up to seven actors, whom all need to add or approve specific information, can be involved in a single project. Organizing the information sharing practices and corresponding technical systems accordingly is difficult. The chapter is concluded with an overview of the information needs (Section 4.6 of stakeholders involved in the creation of a CRU. The main conclusion is that heterogeneous climate markets trade different units, maintain different governance rules and operate under different technological systems. Altogether, Chapter 4 sets the stage for the next step of the analysis, which is the delineation of the technical dimension.

4.1 ISSUES IN GLOBAL CARBON MARKETS

In the introduction the multitude of issues in the carbon markets were briefly covered. Due to the infancy of the VCM it has been dealing with growing pains. Overall, the integrity of the voluntary carbon markets need to be further improved [Blum, 2020]. Currently, the market is lacking a strong governance body to decide on participant eligibility, strengthen validation and verification processes, and combat fraud or money laundering [Adams et al., 2021]. Fragmentation has been inherent to the growth of carbon markets with the multitude of standards maintaining different verification and certification [Reuss et al., 2022; Schneider et al., 2018]. Likewise, project developers defined their own rules on how to measure and verify achieved emission reductions. The additionally of many projects has been highly contested and thus the question was raised if the emission reductions were actually 'real' [Lang et al., 2019; Blum, 2020]. To ensure the integrity and functioning of the market, strong governance is required across three dimensions: i) participant eligibility, ii) participant oversight, and iii) market functioning [Adams et al., 2021].

Apart from double counting, the carbon markets experience more obstacles hindering their growth and maturity. The difficulty in creating insight in these obstacles is that they are more often than not linked to each other. From analysing the literature the following figure has been constructed, trying to capture the current issues of baseline-and-credit, voluntary carbon markets.

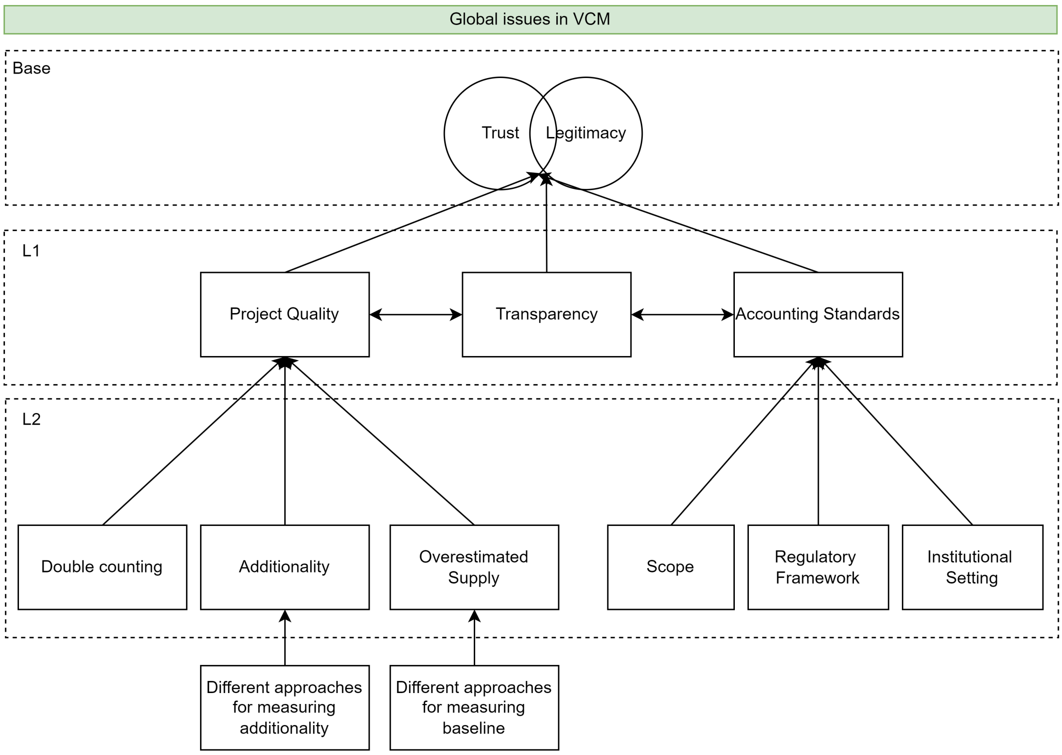

Figure 4.1: Typology of issues in the VCM

Figure 4.1 shows that trust and legitimacy are at the top of the hierarchy in the so-called base layer. These both represent the values crucial to the functioning of the carbon market. Carbon offsetting is based on buyers trusting that the carbon emissions reductions are real and verifiable, if this turns out not to be the case demand will fall, prices drop and the market mechanism is lost [Blum, 2020; López-Vallejo, 2022; Adams et al., 2021]. This phenomenon has already happened once in the compliance market when the quality of CDM projects became too contested [López-Vallejo, 2022; Lang et al., 2019]. Therefore, these values (more or less representing the same) are key.

Layer one shows that trust and validity of the market are largely based on three categories, namely (1) project quality, (2) transparency and (3) accounting practices. A recurring theme is that these three categories are largely interrelated and influence one another. For example, the more aligned the accounting standards of different offset projects, the easier it is to compare among credits and thus the better the transparency [Gifford, 2020; Schaltegger and Csutora, 2012]. On the other hand, the better the project quality, the more transparency is provided in the methodologies used to measure e.g.additionality and supply. Interestingly, in literature and reports double counting is mostly grouped under project quality however double counting is largely based on accounting principles.

It can be observed that in layer one of the figure third party verification is listed in the top right corner. This is to illustrate that third-party project verification can influence both the quality of projects, transparency in the market as well as streamline accounting practices. For this to happen however, strong third-party verification needs to be established. This independent third-party can play a fundamental role in verifying the credibility of the additionality of claimed emission reductions [Kollmuss et al., 2008].

The lowest layer of the figure depicts the palpable problems influencing the layer one concepts and base layer values. Evidently, these problems could be dissected even further, however this is not necessary for a better understanding of double counting. Figure 4.1 is a robust, schematic way of presenting the bidirectional influences of the elements in carbon markets. Table 4.1 provides a more detailed explication of the issues discussed above.

Table 4.1: Consolidation of issues in Voluntary Carbon Market

Issues in the market from articles	**Elements related to issue in the literature**	**Articles mentioning the element**
Lack of transparency		
	Lack of consistent tracking rules	Kollmuss et al. [2008]; Schneider et al. [2018] Blum [2020]; Lang et al. [2019] Matsumoto [2019]
	Transfer of units	Adams et al. [2021]; Schneider et al. [2018]
	Lack of common accounting framework	Adams et al. [2021]; Schneider et al. [2014] López-Vallejo [2022]; Ascui and Lovell [2011] Holman Fenwick Willian LLP [2021]; Poolen and Ryszka [2021] Reuss et al. [2022]; Kreibich and Hermwille [2021]
Quality Assurance		
	Contested Additionallity	Blum [2020]; López-Vallejo [2022] Schneider et al. [2014]
	Contested Social Benefits	López-Vallejo [2022]; Blum [2020], Schneider
	Inaccurate Accounting Methods	Adams et al. [2021]; Schneider et al. [2014] Kollmuss et al. [2008]; Shrimali [2021]
	Differing Baseline Methodologies	Kollmuss et al. [2008]; López-Vallejo [2022], Schneider et al. [2018]
Approval process		
	Conflict of interest auditor/project developer	Adams et al. [2021]; Kollmuss et al. [2008]
	Lack of third-party project verification	López-Vallejo [2022]; Schneider et al. [2014] Blum [2020]; Reuss et al. [2022]
	Inconsistency in third-party benchmarks	Adams et al. [2021]; López-Vallejo [2022] Blum [2020]; Schneider et al. [2014]
	Fundamental differences among standards how projects are reviewed and approved	Adams et al. [2021]; Schneider et al. [2014]

Transparency is crucial in for the VCM to mature since it is one of the main factors influencing trust. Yet creating transparency in the carbon market is hard due to the entangled supply chains, differing offset projects accompanied by their own accounting methods and multiple definitions of carbon credits.

4.2 FORMALISATION OF GLOBAL STAKEHOLDERS

Considering the drivers of the VCM established in the previous section, a clear understanding of the existing relationships between market actors and how this relates to the market mechanisms is necessary. Accordingly, this section maps and categorized the actors in the global carbon market. Both compliance and VCM actors are included to gain appreciation for the complete picture.

Figures 4.2 presents the actors and their relationships, either hierarchical or bidirectional of all the important players within the global carbon market. On the right side of the figure the legend can be found which clarifies the nature of the relationships depicted in the chart. The chart can be interpreted from top to bottom in a hierarchical manner, the actors at the top have most power and/or resources which relatively decrease as one moves down to the bottom of the figure.

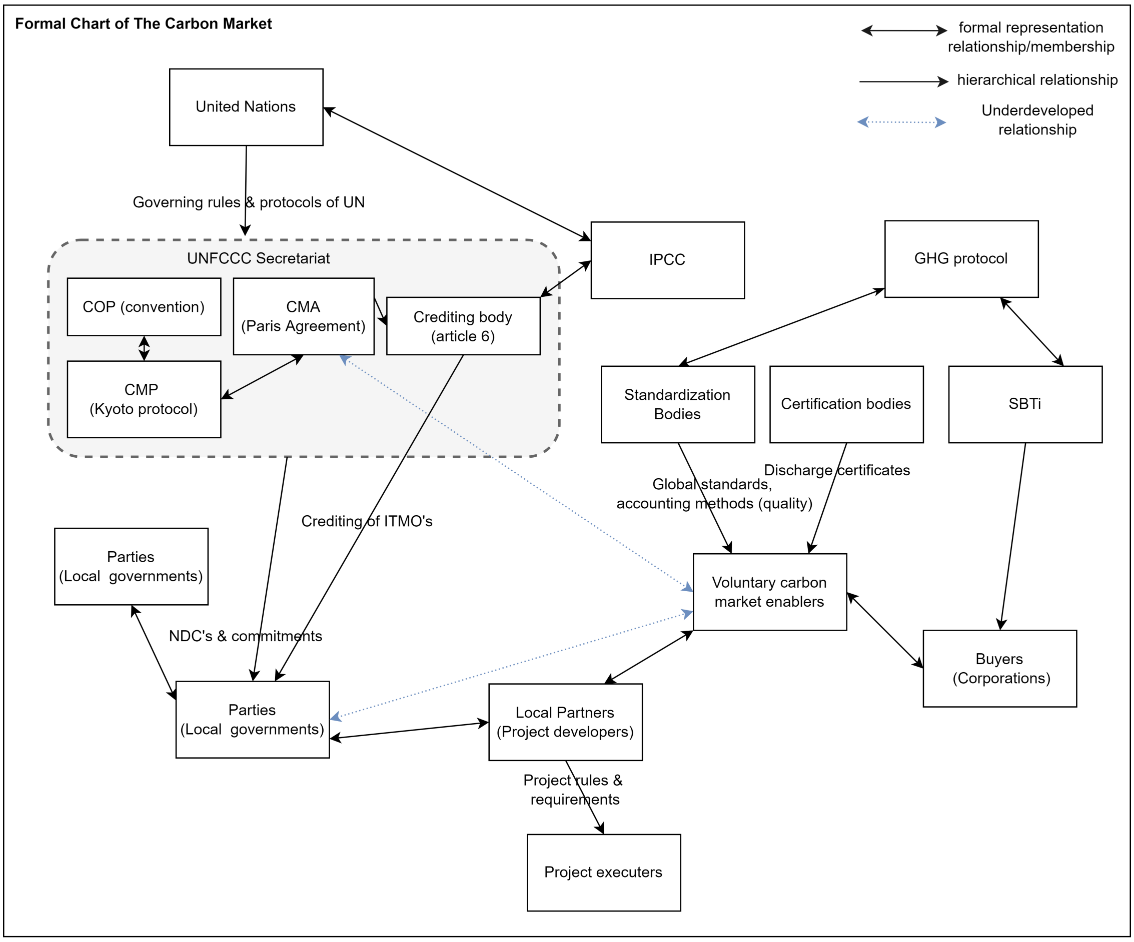

Figure 4.2: Formal chart global carbon market

Government agencies
The figure shows that the United Nations is 'on top' of the hierarchy, enforced through the establishment of the UNFCCC. The UNFCCC secretariat (UN Climate Change) is the United Nations entity tasked with supporting the global response to the threat of climate change. As can be observed in figure 4.2 the UNFCCC consists of various bodies working together to execute the climate strategy. The COP is leading in determining the guidelines and taxonomies shaping the compliance (and to some extend the voluntary) carbon market. Additionally, the formal chart (Fig. 4.2) depicts the governance bodies as one since they perform similar actions in the bigger picture of the carbon market. The most prominent governance bodies are the UNFCCC and IPCC.

Moreover, the International Panel on Climate Change (IPCC) and the crediting body for all credits sold through article 6 of the Paris Agreement like to collaborate. The IPCC is the United Nations body for assessing the science related to climate change. They prepare comprehensive assessment reports about the state of scientific, technical and socio-economic knowledge on climate change, its impact and future risks, and options for reducing the rate at which climate change is taking place.

Standardisation bodies
In the carbon markets accounting plays a key role. International standardization bodies such as the Science Based Targets initiative (SBTi) and the GHG protocol play an important role in standardizing carbon accounting and disclosing. The GHG Protocol provides the world's most widely used greenhouse gas accounting standards for companies. It establishes comprehensive global standardized frameworks to measure and manage GHG emissions from private and public sector operations, value chains and mitigation actions Greenhouse Gas Protocol [nd]. As can be observed in 4.2, the GHG protocol acts as a bit of an island, many companies use their standards and protocols but they do not have any direct formal ties with other governing bodies except for the SBTi.

SBTi is part of the World Resources Institute for sustainable business, aiming to define and promote best practices in emission reductions and net-zero targets in line with climate science as well as providing target setting methods and guidance to companies to set science-based targets in line with latest climate-science SBTi [2022]. The SBTi and GHG protocol are closely linked and often work together.

Figure 4.2 does not yet include technology providers, due to the high-level scope of the formal chart. Technology providers start to play a role when zooming in on the voluntary carbon market enablers. The technology providers generally provide scalable blockchain solutions, which can either be customized or be a more rigid product offered. Depending on the inclusion and design of API's, a blockchain solution can be more or less interoperable with other systems. Choosing how a market enabler or UNFCCC party would implement a blockchain solution either by making their own blockchain technology, rely fully on a technology provider or partially influences the market and players involved. After the mapping of the stakeholders, the next part will focus on analyzing the dynamics of the stakeholders in the global carbon market.

4.2.1 Global Stakeholder Dynamics

van Engelenburg et al. [2020] argues that to develop blockchain-based systems, the complexities and specificity's of the business & government information sharing domain are key for understanding the design options. To understand the complexity of the wider context, the actors from the global carbon markets are grouped in the categories defined by van Engelenburg et al. [2020]. Extending on the formal mapping of relations and players in figure 4.2 in Chapter 4.

Table 4.2: Typology of actors in global carbon market

Stakeholder Categories	Actors
Government Agencies (G)	
Regulater role (gs)	United Nations COP CMA Crediting body Parties (local governments)
Supervision role (gs)	UNFCCC IPCC Parties (local governments)
Businesses (B)	
	Voluntary Carbon Market Enablers (Banks etc.) Corporations (Unilever, Shell etc.)
NGO's (N)	
	WRI/WBcsd - SBTi ICVCM/TS VCM
Technology providers (T)	
	Polygon Ethereum Etc.
Standardisation bodies (S)	
	GHG protocol VCMI IETA/ICROA Standards (Verra, CAR etc.)

Government agencies (G) can act in the role of regulator or as supervisory body, as can be observed from table 4.2. In the supervisory role agencies are interested in receiving additional information from businesses to perform their supervision processes, like compliance management. This translates to the work of the International Carbon Reduction & Offset Alliance (Icroa) looking to provide quality assurance in carbon offsetting. The IPCC is categorized as having a supervision role, since their scientific assessments on climate change are what regulators base their policy-making on. These scientific assessments are based on climate, socio-economic and environmental data, like emission factors used for estimating greenhouse gas emissions [IPCC, nd]. This translates directly into the business cases of the businesses in the carbon market, hence the IPCC is classified as supervisory.

The united nations, and government agencies under the UNFCCC are grouped under the role of regulator as they issue regulations or adopt policies to stimulate developments. The COP is responsible for making international agreements and policies with respect to climate change, giving body and guidelines to established regulations. Despite bodies of the UNFCCC being listed as government agencies, The UNFCCC itself is also grouped under the supervisory role since they to require parties to submit their mitigation pledges each year for review. As such they supervise whether the linked parties are committed to their pledges and are compliant.

Parties (local governments) are grouped under the regulatory role since they design and implement policy for climate mitigation on a national level for their own countries. Again it can be argued that parties also fall under the supervision role since they are responsible for ensuring that companies are compliant. Table 4.2 shows that for technology providers there are not just a few parties at play in the global market. Since no party has successfully established a market wide solution for tokenizing carbon credits, many blockchain initiatives are exploring the possibilities and trying to be the best and first. Known blockchain initiatives are Chia, Toucan and Quantoz but there are many more (interviews). For the analysis it is good to understand that the technology providers side is fluctuating in its players.

Lastly, the standardisation bodies are the GHG protocol, the **wri!** (wri!) - SBTi, the VCMI, the standards issuing credits and the IETA/Icroa. The GHG protocol is one of the most important players since they provide the most widely used accounting standards. Specifically, the role of the standardisation bodies is becoming increasingly important. One of the issues identified in Chapter 4 is the lack of a strong standardization body that unifies the voluntary carbon market, which makes the stakeholder dynamics more important. It would be most logical if the UNFCCC would come forward and become the overall standardisation organism. However, during the last COP the UNFCCC again did not want to partake in the VCM. Their focus is on organizing the **pa!** impermeable, such that the **pa!** becomes inevitable and all countries will have to join sooner rather than later. They view the VCM as secondary and argue that it should operate around the rules set for the compliance market. One pitfall of this strategy is that countries are currently free in deciding which sectors they will use for mitigation pledges allowing for accounting standards to differ greatly. Such pitfalls allow for double counting to occur.

Another aspect from this position of the UNFCCC is that they are the only party with both the resources and recognized objectivity to be able to regulate the VCM. Parties like the WRI - SBTI, ICVCM/TS VCM recognize that there is a gap which needs to be filled, however the TSVCM for example originated from the private sector and does not posses the objectivity to act as sole standardization body. The same rationale applies to the issuing standards, which are also not viewed as impartial, impeding them from filling the gap.

4.3 DOUBLE COUNTING IN GLOBAL CARBON MARKETS

Avoiding double counting of emission reduction is a key policy concern for both the voluntary and compliance carbon markets, as it underwrites to the quality of projects. If emission reductions are double counted, actual global GHG emissions could be higher than the sum of individual reporting. As a result, companies and countries alike could appear to reach their mitigation pledges, while total emissions exceed these levels. Not addressing the double counting of emission reductions could undermine mitigation efforts considerably. More importantly, not preventing double counting of emission reductions could set strong disincentives to use international carbon market mechanisms. Hence, the UNFCCC as well as previously identified governance bodies are trying to establish global methodologies and accounting frameworks to prevent double counting [Schneider et al., 2014]. Double counting can however occur in various and indirect ways, which can be challenging to identify.

Addressing double counting effectively requires action in three areas: accounting of units, design of mechanisms that issue units, and consistent tracking and reporting on units [Adams et al., 2021]. Before diving into these solution spaces , the instances in which double counting can occur and the corresponding integrity risks have to be delineated first. In chapter 1 the first definition of double counting was adopted from Blum [2020], namely *the occurrence of two parties claiming the same carbon removal or emission reduction*.

Double counting seems straightforward but is often more complex than not. Due to the many different type of offset projects, project developers and issuing standards heterogeneous market mechanisms emerged. The differences in these mechanisms constrain market integration and scalability. They also add to the complexity of conducting transactions and the identification of double counting. Double counting becomes prominent where multiple mitigation mechanisms overlap over sources or sinks. Also when emission reductions are transferred among entities subject to mitigation targets and accounted towards them. Hence, the aforementioned definition of double counting is deepened through considering Schneider et al. [2014] his definition: *"Double counting occurs when a single GHG emission reduction or removal, achieved through a mechanism issuing units, is counted more than once towards attaining mitigation pledges or financial pledges for the purpose of mitigating climate change."*

The context of **mechanisms**, set by Schneider et al. [2014] is also adopted, in which units, representing the emissions or emission reductions, are issued and can be transferred between countries as well as other entities. Thus including, but not limited to, market-based mechanisms.

units in this definition are only comprised of credits and not allowances. This thesis leaves out the cap-and-trade mechanisms and solely considers credits as defined in section 2.1 issued under the various crediting schemes like the CDM, JI and Voluntary offsetting schemes.

The definition of Schneider et al. [2014] implies the following:

- Double counting is an accounting issue since it refers to the unitised Emission Reduction (ER) being applied multiple times

To better understand double counting Schneider et al. [2014] classified the instance of double counting into four categories:

- *double issuance* occurs if more than one unit is issued for the same emissions or emission reductions. This leads to double counting of emission reductions if the units are used to attain mitigation pledges. This can for example occur if the same project is registered under two different crediting mechanisms or if two different entities, e.g. producer and user of biofuel, request units for the same reductions.
- *double claiming* occurs if the same emission reductions are accounted twice towards attaining differing mitigation pledges thereby leading to double counting of the emission reductions represented by that unit.
- *double use* or *double selling* refers to the situation where one issued unit is used twice to attain mitigation pledges. It could for example occur if a unit is duplicated in registries or otherwise transferred twice to another country [Schneider et al., 2014].
- *double purpose* refers to the situation where a unit is not only used for attaining a mitigation pledge under the UNFCCC, but the financial (or technology) transfers associated with the issuance of that unit are also counted towards financial or technology pledges, such as climate finance or activities implemented under a technology mechanism.

These four generic forms of double counting can, as previously mentioned, occur in various ways. Double purpose does not directly affect global GHG emissions and is therefore considered less of an issue than the other forms of double counting. Double selling is based correct registering and transferring of the credits, directly related to how the credits are registered for, which is generally dependent on the registries used by various standards. This form of double counting is of less concern due to its straightforwardness. Based on the argumentation above, this research will focus specifically on double issuance and double claiming from hereon, since they are identified as most important and hardest to detect [Schneider et al., 2014; Shrimali, 2021; Cörvers et al., 2022].

Another part of the picture is that double counting is also apparent in supply chains emission. Due to climate change consumers require companies to become more sustainable and environmentally conscious [Simon-Kucher Partners, 2021]. As a result, companies are exploring how to make their supply chains more sustainable. They are aiming to become 'net-zero' via a combination of sustainable sourcing and producing and carbon offsetting. The greatest emission reduction opportunities lie in the scope 3 emissions, given that on average the Scope 3 emissions are 5.5 times the amount of combined Scope 1 and Scope 2 emissions [Shrimali, 2021]. Hence, his paper is specifically focused on double counting in Scope 3 or supply chain emissions. According to Shrimali [2021] this type of double counting presents itself in two forms:

1. Double counting inherent in calculating Scope 3 emissions of different actors within a product's supply chain;
2. Double counting that occurs due to entanglement of supply chains of different products

Shrimali [2021] emphasizes the importance of across supply chain double counting, which he argues can be avoided by appropriate allocation of the upstream and downstream emissions. This is in practice very difficult due to the entanglement of global supply chains and scope 3 emission reporting is still in its infancy. Summarizing both the stakeholder dynamics and the definition of double counting, Figure 4.3 captures the heterogeneity existent in the global carbon market. The figure shows that each actor group has a different reporting mechanisms based on different metrics.

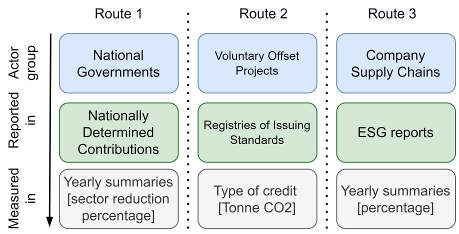

Figure 4.3: Reporting mechanisms per route

Building a comprehensive overview of these definitions and empirical knowledge translated from text reaped figure 4.4. The legend shows that the solid red arrows depict where in the global carbon market and between which instances double counting is happening.

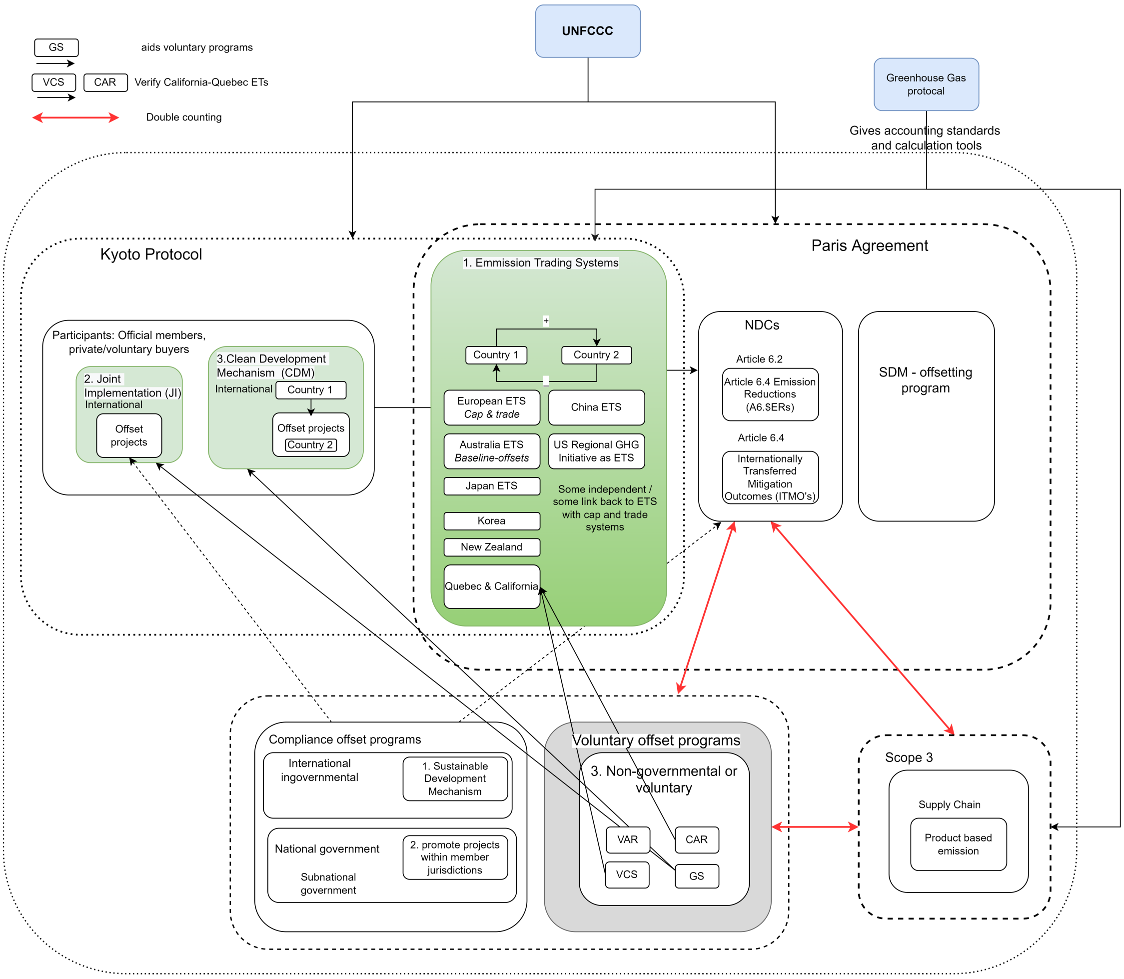

Figure 4.4: Double counting in the global carbon market

The dashed outer line shows shows the carbon market as a whole. On the left the Kyoto Protocol is depicted since as origin of the carbon markets. The Kyoto Protocol transformed into the Paris Agreement which is currently in operation and issuing credits for carbon projects.

The large green box shows the emission trading systems operating next to the voluntary carbon market, in which most markets are based on cap & trade principles in which corporations can trade their emission allowances.

At the bottom of figure 4.4 the voluntary carbon market can be observed in the grey box, with corresponding voluntary certifiers. What can be observed from the picture is that the identified forms of double counting, double claiming & issuance, are happening between the NDCs, voluntary offset programs and scope 3. The grey box also shows that the offset programs executed under either the compliance or voluntary market can be grouped together. This is due to the fact that the voluntary market arose based on the compliance market, hence these projects adhere to similar accounting standards which makes it easier to compare individual projects.

In a fragmented carbon market, with multiple mechanisms under international, bilateral, national or non-governmental governance, there is a risk that two mechanisms issue units for the same emissions or emission reductions. For example, the same project could be awarded credits under a mechanism under domestic governance and a mechanism under international governance. The other problematic instance is that an local party committed to the Paris Agreement claims emission reductions, which actually have been instigated by voluntary carbon offsetting projects and are generating carbon credits in the VCM. This will be elaborated on in the following section.

4.4 DOUBLE COUNTING RELATED TO ACORN

As depicted in Figure 4.4, three forms of double claiming are experienced by the global carbon market. As Acorn falls under the stakeholder category of voluntary offset projects, the global figure of double counting is translated to a figure (See Figure 4.5 illustrating double counting in relation to Acorn. Figure 4.5 is composed based on the literature review and empirical knowledge provided by Rabobank Acorn.

- Double claiming of carbon removals between the Voluntary Carbon Market, the nationally determined contributions NDC and companies accounting for their scope three emissions.
- Double claiming of carbon removals between different supply chains, both purchasing from the same farmer, who is actively removing carbon through for example agroforestry.
- Lack of guidance ensuring fair treatment of farmers who are accounted for as a scope three supplier. If farmers are considered in a company's scope 3, they can't participate in the Voluntary Carbon Market and receive payments for their ecosystem services.

All of the issues identified above, in combination with the definitions of double counting in the literature are translated into figure 4.5. Considering the focus of this thesis on evaluating Acorn's blockchain solution, the double claiming of carbon removals between different supply chains is not considered in the description of double counting given below.

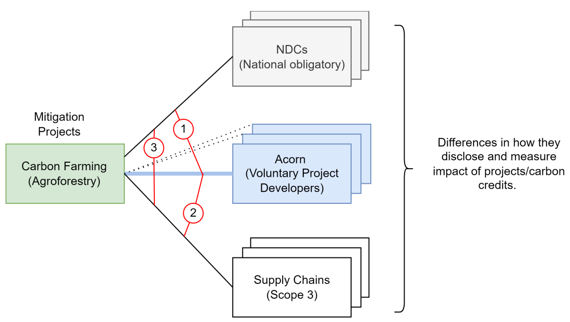

Figure 4.5: Depiction of the possibilities of double counting between actors

Looking at figure 4.5, it can be observed that double counting is happening on three levels. The three numbers depict the possibility for double counting to occur. The dashed lines behind Acorn illustrates the multiplicity of project developers active in the VCM. The supply chain box depicts the scope 3 carbon accounting and the accolade shows that the difficulty of reporting on and conglomerating of different methodologies. The thick blue line indicates the relationship between Acorn and the farmer. This line illustrates that double counting between one farmer and Acorn is prevented by current registering and accounting practices. Considering a single farmer and a single project developer that reports on a single registry, double counting is easily prevented. Moreover, if for some reason double counting occurred it is easily detected. The multiplicity behind the three boxes illustrate the complexity accompanied by the many actors in the VCM. Below the three forms of double counting are described in more detail.

1. Double claiming between a voluntary project and NDCs

In this case a voluntary carbon market project is established and begins to issue carbon credits. A voluntary buyer, for example a corporate, purchases those carbon credits and counts them towards a voluntary 'carbon neutrality' claims. In this case,the unit may also have been inadvertently captured in the host country inventory, thus creating a second claim towards a target when there is in fact only one [Schneider et al., 2018].

2. Double claiming between Supply Chains and Voluntary Projects

The carbon sequestered on farmland can only be claimed as a VCM credit if it demonstrates Additionally. Supply chain carbon accounting however does not follow this principle, nor does it check for double claiming in its protocols. This can mean that carbon finance decarbonized the supply chain of a corporate, and this corporate is in turn selling its product as carbon neutral. This might not seem like double counting due to the wildly different approach to accounting, but the real question is: would the corporate have invested in decarbonization elsewhere in the supply chain if their farmer suppliers had not already done so? If the answer is yes, then double claiming becomes an issue, as one intervention is counted twice and therefore another decarbonization intervention has not been performed.

3. Double claiming between NDCs and Supply Chains

In the case of double claiming between NDCs and supply chains, there is hardly a solid foundation to build carbon accounting discussions on. Scope 3 accounting disregards national boundaries and NDCs only consider projects within their borders. Neither accounting principle (if any) recognizes the risks of double claiming, so neither will pursue prevention of double claiming. Again the question arises: would either the country or the supply chain actors have decarbonized elsewhere if they did not claim this carbon reduction/removal? If the answer is yes, one is dealing with problematic double claiming.

In conclusion, the double claiming of route 1 would be 'easiest' to prevent. Considering that the farmer is located in one country, this can be accounted in the NDC of that country and they could align with project developers like Acorn on measuring, accounting and disclosing. If these and then this issue could hypothetically be solved very well. Here, Corresponding Adjustments are also a solution, as most countries are unable to pay for these interventions without private sector finance. The issue of double counting with supply chain scopes included is more intricate, as these carbon offsets or reductions are not specifically linked to one country and one project because of the reach of companies and ownership allocation. Hence, this is harder to prevent. The thick blue line indicates that Acorn is able to organize its own processes sufficiently, solving the issue of double counting very well. Acorn is certain that no trees existed before they embark on a new project in a new location, since all VCM projects need to register their credits. However, at present it is impossible to solve the interactions with (2) the supply chains of companies, and (3) governments with their NDCs for Acorn alone.

In conclusion, the background on carbon markets in Chapter 2 and the demarcation of double counting emphasise that different climate markets trade different units, have differences in structure and governance, and rely on separate, centralized registries. The result is a multitude of schemes trading instruments within closed technological systems (with centralized registries) and differing rules, such as those associated with monitoring, reporting and verification (MRV).

To prevent double counting and simultaneously facilitate the growth of the VCM;

1. A new or improved information sharing architecture is needed.
2. There is a corresponding need, also, for the capability to generate, manage, and harmonize information representing the outcomes of GHG mitigation actions across multiple industry sectors and governmental jurisdictions [Baumann, 2018].

4.5 ACORN GOVERNANCE MODEL ANALYSIS

The previous half of the chapter outlined the issue of double counting in its global context and how this relates to project developers like Acorn. The heterogeneity among carbon schemes related to structure and governance was highlighted. The next half of the chapter will zoom in on Acorn to investigate what actors are involved, how these actors collaborate and which information is shared among them. Analysing such information flows for a single project developer helps to investigate low-level information sharing requirements. From this bottom-up analysis, extensible information requirements and considerations can be derived for the global market. These considerations will help to evaluate the blockchain solution of Acorn in 5. Section 3.3 already provided the context of Acorn, as such the analysis starts directly with the mapping of Acorn's value exchanges.

4.5.1 Acorn Stakeholders

Figure 4.6 depicts the value exchanged between Acorn and the other stakeholders involved. The picture is based on the current processes of Acorn. As can be observed in the figure Acorn's general operations involve collaboration with many parties. Below a description is given of the nature of each relation and what value is exchanged.

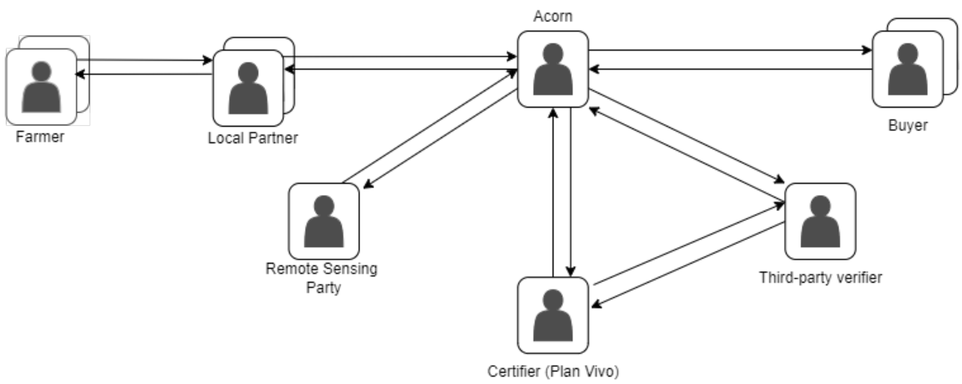

Figure 4.6: Current Value Model Acorn

The motivation of the farmer is that with participation in Acorn projects have a stable income throughout the year as well as increased protection for their crops. The planting of trees can positively impact the growth and survival of crops by providing protection for storms as well as. The farmer also benefits of education provided by the local partners on soil, vegetation and tree maintenance specifically designed for their ecosystem [Rabobank, 2021].

The local partner is responsible for governing all processes on their project site. Local partners can be NGO's, farmers' co-ops, trading companies or corporations. The local partner must outline a clear implementation and monitoring plan before joining the network [Rabobank Acorn, 2021]. They maintain the relationship with the farmers, are responsible for gathering the necessary data on the farmers as well as provide support for the farmer in learning afforestation or offer the training themselves. The local partner is offered 10% of the revenue originating from the projects being deployed, in exchange the local partner handles all local organizational matters. For Acorn the dependency on these local partners is grave and reasonable trust is required for this arrangement.

The verification step provides the quality assurance of the removal/sequestration projects. Acorn's projects are first validated by local bodies whom have sufficient experience in the local ecosystem. Then they are verified by approved organizations with documented experience in auditing GHG projects and accredited by proper authorities like the CDM [Rabobank, 2021]. Important to note is that this verification does not include reporting and evaluation of a projects' socioeconomic benefits. The verification happens every three years by independent (third-party) verifiers.

Acorn has teamed up with a remote sensing partner to calculate the sequestered carbon remotely. Acorn pays for the services provided by the remote sensing party and in exchange they deliver the satellite images along with the final calculations. The specific methods used by the remote sensing parties are kept confidential since this is part of their own intellectual property, which their business case relies on. Acorn has also been working on developing their own remote sensing capabilities. They have been successful and since then part of the capacity for the remote sensing is also in-house, the remainder is still outsourced to remote parties. Acorn makes use of two remote sensing parties, namely X and X. The remote sensing capabilities require computing power and if Acorn would want to expand their remote sensing capacities they would need among other things to increase their computing power notably.

The Plan Vivo Foundation is the certifier of the Acorn program. Plan Vivo is a certification body that certifies projects against the Plan Vivo Standard. Plan Vivo is internationally recognised as the leading standard for community land-use projects. Certification under Plan Vivo demonstrates to the market that a project is sustainable over the long-term, is beneficial to people's livelihoods and provides both climate and environmental benefits [Plan Vivo Foundation, 2020].

The value exchanged is that Plan Vivo executes the verification to determine if the methodology is properly applied and that the project requirements are met. With the approval of Plan Vivo, certified credits can be issued. In return Plan Vivo receives a reimbursement for their efforts. Plan Vivo as a standard serves in two ways. In the wider context of the carbon market, the standard also functions as a registry for all the credits they certified as well as performing the certification itself. The demand for carbon credits is high and has been growing over the last couple years [Forest Trends' Ecosystem Marketplace, 2021]. Acorn interacts with the demand side of the carbon market (right side of 4.6), by encouraging corporations to offset their emissions by buying credits from Acorn's platform, which provides the desired traceability and transparency throughout the supply chain.

As part of the governance structure, these relationships are documented in a series of contracts between Acorn and the stakeholders [Rabobank, 2021]. Figure 4.6 depicts the five contracts in place which formalize the relationships depicted in the current value model (Figure 4.7). These contracts formalise the agreements, for example on the eligibility of the farmer with respect to property rights, income and community consequences. The contract between the local partner and Acorn ensures the benevolence and necessary capacities of the local partners as they head the projects offline.

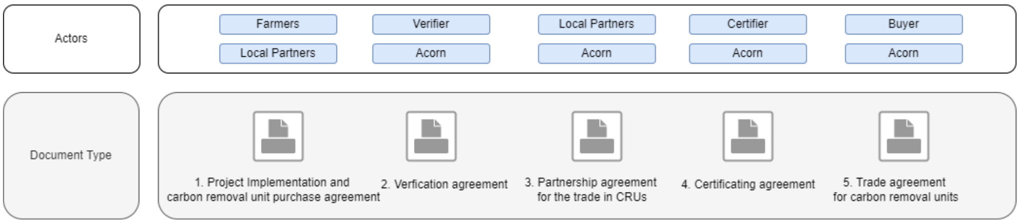

Figure 4.7: Contracts constituting Acorn's governance

The analysis showed that Acorn has to organize its collaboration with five actors for a single offset project. Per offset project, different farmers, local partners (and possibly certifiers) and buyers are involved. The certifier stays the same for Acorn's projects since they developed the methodology used to calculate the carbon sequestered together with Plan Vivo. The key take away is that the organization of offset projects is heavily information based and labour intensive.

4.5.2 Scale

Essential to understand is that Acorn simultaneously operates on local levels and global levels, considering the multitude of the local parties and farmers at the beginning of the supply chain and the buyers on the other side of the supply chain. This global outlook, and the shifting from local to global and intermediate levels can be observed in figure 4.6. Acorns' current projects are located in Brazil, Colombia, Nicaragua and Peru in Middle- and South-America and in Uganda, Tanzania and the Ivory Coast in Africa.

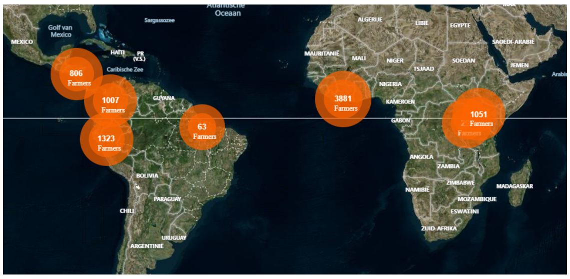

Figure 4.8: Acorn projects around the globe

From the supply side, the farmers are growing the trees in the countries of the projects' origin. Likewise the local parties are operational in the same country as the farmers and in close proximity, whom report to Acorn on a continuous basis. This link between the multitude of farmers and a local party is replicated in each country in which projects have been established. Taking into consideration the buyers, theoretically any company located anywhere could buy a CRU of Acorn. Translating this into a lifecycle of a CRU from beginning to end the process is similar to a diverging and converging funnel, progressing from a local to global stage, as the CRU matures and reaches the end of its lifecycle (see figure 4.9).

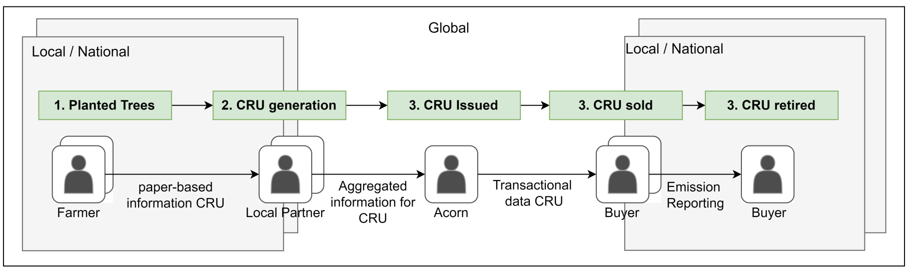

Figure 4.9: CRU lifecyle

This going-back and forth between local and global levels for an intangible asset, transformed into a certificate, begins to illustrate the difficulty in providing transparency and traceability.

4.6 INFORMATION NEEDS

The past sections explicated how Acorn operates, what parties are involved and how the governance is arranged. In order for double counting to be prevented, the Monitoring, Reporting & Verficiation (MRV) practices among carbon markets have to become aligned. As mentioned, methodologies to calculate captured carbon can differ per project developer and type of project. To understand how a CRU is minted in Acorn, the properties are examined and a business process model is made to depict the information exchanges between Acorn and its partners.

4.6.1 Key Properties of CRUs

One of Acorns pillars is providing transparency in the process of generating, issuing and selling their carbon credits, through thorough and open documentation of their methodologies and traceability of the carbon credits. This transparency into the actions performed requires a certain amount of visibility in the data on which the actions are based. Acorn has already taken steps in increasing transparency by publishing their methodology and framework. Figure 4.10 provides an overview of the properties Acorn CRUs consist of.

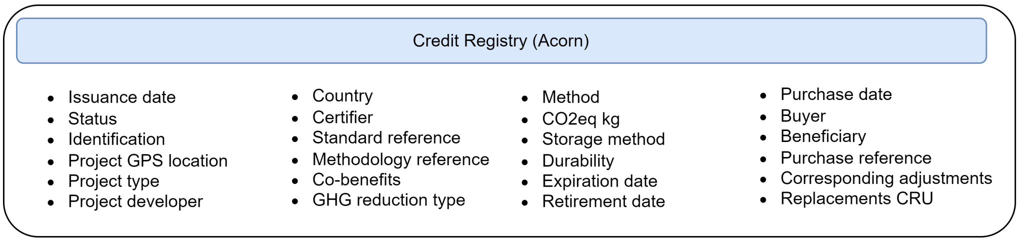

Figure 4.10: Information Required for CRUs

What can be seen in Figure 4.10 is that all parties involved in the creation of a CRU are documented in its properties [Rabobank, 2021]. On this end the information is very transparent. The real difficulty in preventing double counting presents itself in discerning the location of specific projects, which can be reduced to the polygons[1] that demarcate project sites in agroforestation projects.

4.6.2 Business Process Model CRU generation

A business process model is valuable in helping to contextualize and visualize a process such that the business process can be understood and refined [Figl, 2017]. Hence, the business process model in 4.11 was developed of Acorn's current process, to illustrate what parties and information from whom is required to represent the digital formation of a carbon credit. An extended version of the Business Process Model, including the information flows from third-parties and additional explanation can be found in Appendix C.

The main steps throughout the process consist of gathering information on the offset project. First the data is gathered from the local party, next the calculations from the remote sensing party are added. The data gets accumulated and the necessary details are provided to the remote sensing party. Acorn can also make use of its own remote sensing capabilities, but for the comprehensibility of the figure this option was left out. The remote sensing party receives the details of the project, and bases its calculations on the satellite images and corresponding polygons.

1 A location polygon is a shape that represents a point of interest using geospatial coordinates.

When the calculations have been approved and screened by Acorn the project can be certified, the certifier decides whether the project receives additional verification. After all these steps have been performed and the certification was successful Acorn reviews the data one last time and then the CRUs are put on the registry. This process model of the creation of CRUs is repeated for every project that is developed by Acorn.

Important to note in 4.11 is that the data of the farmer is provided by the local partner, as the farmer is limited in its digital resources. At present, it is more efficient and reliable for the local partner to report this information to Acorn than to have the farmer report it. Moreover, it is evident that the creation of a CRU requires data from several different parties to be aggregated. In its current form, the process has built in checks by Acorn to guard the data accuracy. For example the calculations are confirmed and if necessary Acorn applies margin errors on the calculated amount of carbon sequestered. Lastly, before a CRU is put on a digital ledger Acorn handles all the information and is able to modify any irregularities.

The business process model shows that it is desirable for Acorn keep in control of the data to ensure its accuracy, which is important for market quality. On the other hand, the process is resource intensive, requires human interference and becomes less transparent. Combining this with the needs identified to solve double counting leads to the following considerations:

- A new or improved universal information sharing system is needed,
  - which facilitates transparency by nature, from bottom up project developers to top-down issuing standards and their registries;
  - Such a system needs to support data accuracy as well as reliability;
  - And ideally the information systems facilitates some automation of processes
- There is a corresponding need for the capability to generate, manage, and harmonize information.

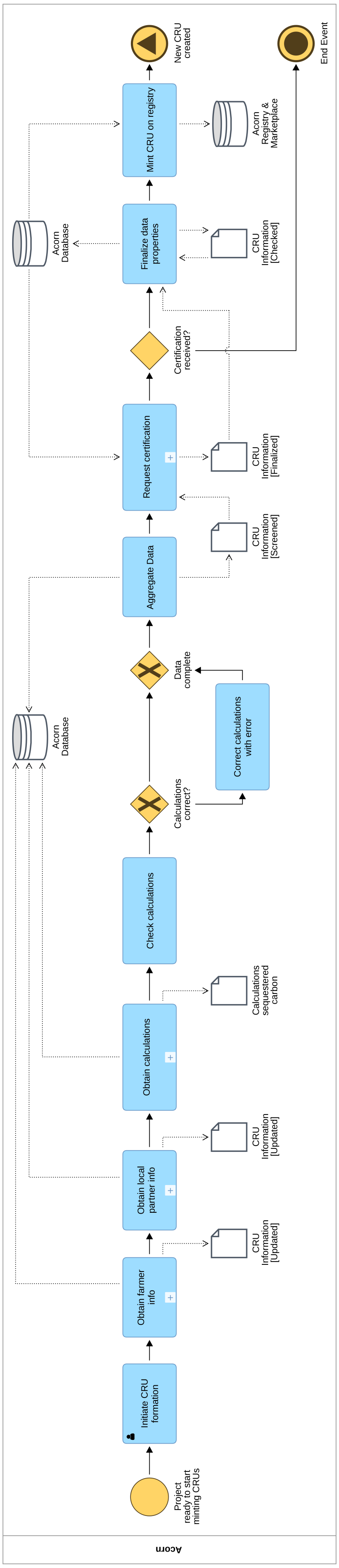

Figure 4.11: High-Level Business Process Model Acorn

4.7 CONCLUSION CHAPTER 4

As sub-question 1 indicated, the output for this chapter is the definition of double counting, guided by the analysis of stakeholder dynamics. The scene for the wider context is set by (1) delineating the stakeholders in the global carbon market and (2) describing double counting in the global carbon market. The desk researched used secondary information sources, and empirical information to delineate the issue of double counting. Literature was used to explore current definitions of double counting and identify what forms of double counting exist. This knowledge was then extended by empirical information gained from Acorn and a multitude of reports, webinars and websites. Overall, chapter 4 elicited influential concepts from the literature that can support the evaluation efforts and lead to the development of innovative and well-grounded recommendations. Hence, this chapter provided the answer sub-question 1: *"What is the problem of double counting taking on both a broader stakeholder and Acorn specific perspective?"*

In the global carbon market, universal standards are lacking which leaves it possible for double counting among different mechanisms to occur. There is a need for a strong governance body able to streamline the different accounting practices and methodologies, achieve stakeholder alignment and universal definitions is similarly lacking Baumann [2018]. The UNFCCC would be the most convincing actor, due to their impartiality and relations with the UN, yet the UNFCCC does not desire to govern the VCM [Franke et al., 2020; Rabobank, 2021]. Their focus is on improving the **pa!** such that all countries will join and become local parties, abolishing the need for a VCM. Other actors are trying to fill this gap, e.g.the initiative of technology providers by aligning on the properties used for tokenizing carbon credits. Private initiatives such as the TSVCM, or SBTi are too positioning themselves to be standard-setters. However, such actors are not impartial enough to be acknowledged globally, as they operate from a they are private parties with a profit motive. Solving double counting requires collaboration from both local parties of the Paris Agreement (i.e.governments) and the UNFCCC, along with willingness from standards, companies and other market enablers to align their processes [Adams et al., 2021].

From Acorn's perspective, it is most important to maintain the quality of their own supply. In this context, double counting is not an issue that requires attention as their registry captures all their projects and double counting is easy to prevent. Nevertheless, as Acorn aims to be exemplary in providing transparency and traceability in the voluntary carbon market they gain from preventing double counting occurrences 1 and 3.

Essentially, there are three routes in which carbon offsets are allocated: supply chain accounting, voluntary carbon accounting & NDCs. All three routes use a different type of allocation of the source of carbon removal as well as to whom the removal is assigned. The source of emission removals can however always be traced back to the GPS polygon on which the project has taken place. What is necessary in order to prevent double counting is the stripping away of accounting principles and return to the source; when is carbon removed and sequestered from the atmosphere, before such removals can be assigned to a party.

From the delineation of double counting and the stakeholder analysis several conditions to solve double counting materialized;

A new or improved universal information sharing architecture is needed,

- This requires transparent information systems, from bottom up project developers to top-down issuing standards and their registries;
- Such information systems need to support data accuracy as well as reliability;
- And, ideally the information systems facilitates (some) automation of processes

Also, there is a corresponding need, for the capability to generate, manage, and harmonize information [Baumann, 2018], in which accounting practises should be better aligned by returning to the source of emissions: *the GPS polygon*.

5 TECHNICAL DIMENSION

Chapter 4 established the mechanisms underlying double counting and identified the need for the VCM to ameliorate its legitimacy. Better information-sharing architectures are required and in the extant literature, blockchain is repeatedly suggested as the innovative technology to fill this need. However, The buzz around blockchain often results in individuals advocating for the application of blockchain technology whilst lacking a thorough understanding of the technology itself. Hence, this chapter sheds light on the technical dimension related to double counting in the VCM. Thereby, this chapter answers sub-question 2: *What are the key features, benefits, and limitations of blockchain architecture with respect to the prevention of double counting?*

A basic understanding of blockchain technology and its applications is established in Chapter 2. Chapter 5 builds on this knowledge to recognize in what manner blockchain could pose as a solution to to prevent double counting. To start with, the suitability for blockchain technology in the carbon market is illustrated in Section 5.1 based on literature. Evidently, the process of creating a carbon credit can be viewed as a supply chain [Ashley and Johnson, 2018; Wang et al., 2020; Khaqqi et al., 2018]. The market requires more insight into the sourcing and trading of the credits similar to e.g.food products, clothing and logistics [Fu et al., 2018; Khaqqi et al., 2018; Li et al., 2021]. The possibility of blockchain technology to offer transparency and traceability in supply chains has been an increasing topic of interest in literature [Agrawal et al., 2021; Francisco and Swanson, 2018; Dobrovnik et al., 2018; Wang et al., 2020]. Moreover, theoretically blockchain can offer the security, immutability, visibility and automation desired, also with respect to the monitoring, reporting and verification purposes.

The benefits and limitations of blockchain to prevent double counting are discussed in Section 5.2. The primary concept is that blockchain technology in itself already has the potential to considerably reduce double counting from occurring, due to its immutable, transparent, efficient and secure nature. Key features of blockchain that can be enlisted to prevent double counting are smart contracts and asset tokenization. To what extent blockchain can prevent double counting depends on how well a carbon credit can be defined on the blockchain, the quality of data entered, and the alignment of mechanisms.

Subsequently, the chapter moves on to the analysis of the blockchain solution of Acorn in which the case study questions (defined in Appendix B.1) helped structure the analysis. In Section 5.3 Acorn's core solution is described and supported by mapping the information flows of the designed blockchain (Figure 5.1). The specific choices for certain configurations are summarized and discussed. The Section discusses the reasoning of Acorn to postpone the implementation of blockchain technology indefinitely and identifies the benefits and limitations of the current design with respect to double counting.

Conclusively, by mapping the solution and evaluating the design choices based on the propositions of the van Engelenburg et al. [2020] framework the thesis answers sub-question 3: *What are the benefits and limitations of Acorn's blockchain solution which can be identified by applying the framework of van Engelenburg?* The chapter closes with a proposal for improvements of the blockchain architecture in Figure 5.2 and an overview of the remaining issues (See Table 8.1, that are associated with the implementation of a blockchain-based platform.

5.1 BLOCKCHAIN TECHNOLOGY FOR THE CARBON MARKET

Actors in the global carbon market are invested in maintaining and improving quality of the market to ensure future existence [Adams et al., 2021; Reuss et al., 2022]. They can do so by increasing transparency in the accounting practices of carbon credits, increasing trust through reliable accounting as well as increasing methodology alignment [Blum, 2020; Cörvers et al., 2022; Schneider et al., 2020]. Such transparency and unification of methodologies can be achieved through the use of an information system that registers all activity in a transparent, traceable and trustworthy manner, based on accurate and valid business data. This suggest that blockchain can pose as the foundation on which the information system could be based, offering functionalities and attributes that could enhance the transparency of international climate action, and address some of the barriers experienced in previous carbon markets [Franke et al., 2020; Zheng et al., 2017; Xu et al., 2017; Wang et al., 2020].

In the extant literature, multiple parties have already designed or discussed a blockchain solution, mainly for ETS-systems [Franke et al., 2020; Khaqqi et al., 2018; Mandaroux et al., 2021; Li et al., 2021]. In the extant literature, blockchain is also seen as the solution for effective linkage of emission markets operating in different countries and or regions [Kim and Huh, 2020]. Another aspect for choosing blockchain is the safety of transactions that the technology offers. Primarily, it is argued that since all trading, monitoring, reporting, and verification of carbon credits and permits can be automatically executed and recorded via smart contracts deployed on a decentralized blockchain it can dramatically reduce administrative costs, improve transparency and traceability, and eliminate double counting and fraud [Li et al., 2021].

The concept of transparency is at the centre of the case at hand. Earlier criticism was focused on the lack of transparency during implementation and validation of mitigation activities. Enhanced transparency is key to safeguard unit quality and environmental integrity of the certificates generated. In the history of the global carbon market, information asymmetry often resulted from incomplete project documentation like the MRV reports Franke et al. [2020]; Lang et al. [2019]. This information asymmetry between project proponents, regulators and auditors altered the accreditation of carbon credits [Franke et al., 2020]. Since the blockchain is a distributed ledger, information stored on the blockchain is accessible to all parties simultaneously if accessibility rights are properly distributed. By forcing all participants to commit the right data, the quality and transparency of documentation is increased, and unit quality can be more easily verified [Franke et al., 2020; Mandaroux et al., 2021].

In section 2.5 the link between supply chains and the value chain of a carbon credit has been established. Azzi et al. [2019]; Francisco and Swanson [2018]; Dobrovnik et al. [2018] advocate the many possibilities blockchain has to offer to improve supply chain transparency, including traceability. Provenance of products is becoming more and more important to consumers. They want to know if their products are farmed, produced or acquired in a fair and sustainable manner, especially when the supply chains are multi-tiered and increasing in global scope [Francisco and Swanson, 2018]. Additionally, for MRV purposes enhanced traceability and visibility is desirable. For the carbon markets addressing such concerns among consumers is equally important. Consumers want quality credits, verified and authenticated by trust-worthy parties, resulting in real emission reductions [Francisco and Swanson, 2018]. Blockchain is increasingly recognized in the extant literature to implement traceability by creating an information trail while ensuring security and data immutability [Agrawal et al., 2021; Azzi et al., 2019; Francisco and Swanson, 2018; Dobrovnik et al., 2018].

Especially the tokenization of assets in combination with smart contracts is particularly interesting for the VCM, even more so non-, and semi-fungible tokens considering they are uniquely identifiable [Wang et al., 2021]. This characteristic is crucial in the digitization of carbon credits and facilitating digital trading mechanisms. Tokenizing the carbon credits into non-fungible tokens can establish the necessary trust and traceability in the carbon credit market.

Smart contracts can then be deployed to facilitate the automatic trading of carbon credits on the blockchain, meanwhile registering all the transactions made, increasing the auditability of carbon credits during their life-cycle [Zheng et al., 2020].

Overall, the suitability of blockchain for the issue at hand is justified. However, a challenge that remains is, defining the 'right' data to be uploaded on the blockchain Kilkenny and Robinson [2018]. This requires more in-depth expertise on the properties of a carbon credit and carbon market mechanisms, which will be further explored in the next sections.

5.2 BENEFITS AND LIMITATIONS OF BLOCKCHAIN TECHNOLOGY IN THE VCM

The conditions to solve double counting established in the previous chapter are transparency in emission reporting of companies and governments as well as in carbon offsetting projects and their supply chains, market-wide stakeholder alignment, traceability of the carbon credits, improved security, unequivocal ownership and decreased room for human error. Blockchain technology itself enables decentralized and transactional data sharing across a large network of untrusted parties. The benefits of blockchain technology are inherent to its characteristics, immutability, transparency, efficiency, and security.

A key feature of blockchain technology to solve double counting is smart contracts, they facilitate the automatic execution of agreements once pre-defined rules have been met. This function reduces risk, administration and service costs and increases the efficiency of business processes. Another key feature is tokenization. Tokenization allows for the representation of a given (financial) asset as a unit on the distributed ledger, such that a user can easily prove the existence and ownership of a digital asset. The benefits of tokenization are full-history tradability, deep liquidity, and traceability.

The main risk of employing blockchain technology for double counting is demonstrated by the saying *"garbage in - garbage out"*, a colloquial recognition of poor quality data entry leading to unreliable data output [Kilkenny and Robinson, 2018]. Essentially, clear cut definitions of real-world asset are required for adequate tokenization. This recognition is crucial for the tokenizing carbon credits. It comes down to the notion that for any digital ecosystem to function correctly, the system and its determinants need to be universally and mutually understood in its real-world setting. Yet, one of the leading issues in the carbon market is the lack of universal standards for carbon credits. Careful consideration is therefore required in advancing the tokenization of carbon credits, acknowledging its complex structures.

Another impediment of using blockchain and in its extension NFTs, is that once an NFT has been minted it can only exist within the same ecosystem or network since the underlying blockchain platform limits the extensibility of the tokens. This is of specific importance for the tokenization of carbon credits, as it directly influences the solution space when theorizing about creating connected registries, bridges between registries or e.g.a meta-registry. Ideally, to prevent double counting at once, one registry or a so-called meta-registry would host all the carbon credits. However, due to the different nature of carbon credits and their project types; removal or reduction, nature-based, technical based etc., one-on-one comparison which is required for hosting tokenizing credits is nearly impossible to realize for all types of carbon credits [Sazandrishvili, 2020; Valeonti et al., 2021].

In short, the relation between double counting and the characteristics of blockchain technology crystallized throughout Chapter 1 & 2 and the . By comparing the conditions to solve double counting, *transparency, stakeholder alignment, traceability, improved security, unequivocal ownership and less room for human error*, to the characteristics of blockchain technology, *immutable, transparent, efficient and secure*, an almost one-on-one relationship can be observed. This comparison implies that double counting can be easily solved by merely putting carbon credits on the blockchain. This is however is a false pretense and should not mislead actors into believing that carbon market issues can be solved by just implementing blockchain. As discussed, clear definitions and constructs as well as corresponding governance requirements of the asset have to be in place to complete the tokenization steps.

5.3 BLOCKCHAIN TECHNOLOGY IN ACORN

In this section, the blockchain-based platform of Acorn will be described. The information of interest in this case is at the hands of Acorn initially. Acorn needs to organize its measuring methodologies, issuance, tracing and trading processes of their CRUs in such a matter that double counting at the hand of others becomes easy to detect, that their credits are comparable, and most desirably that double counting is prevented. It has become apparent in Chapter 4 this can only be achieved through consideration and (possible) collaboration with other actors in the carbon markets. To align the technology fitted to these stakeholder dynamics requires adequate blockchain governance. It is important to mention that the blockchain architecture discussed in the next sections has not been implemented by Rabobank and remains only a theoretical solutions, due to several reasons which will be touched upon later.

5.3.1 Acorn's Proposed Blockchain-based platform

Acorn did the research and designed a blockchain based registry for Acorn. They decided however to put a pause on the project and focus on the supply side. This decision was twofold since firstly, the market was perceived as too immature and ongoing issues such related to double counting remained unresolved: *What should such a registry precisely do to prevent double counting?* and *With whom does Acorn need to compare there credits with? Who are the regulatory stakeholders?* and secondly, the wish to generate a certain amount of supply before up-scaling. A more detailed delineation is given in Section 5.3.4. The strategy lead of Acorn is dedicated to dealing with these types of issues. The focus of Acorn itself is on being as transparent as possible. The more transparent they can be in their practices, the easier it is for other companies to compare themselves with Acorn and improve their own methodologies. This strategy is followed since Acorn cannot exercise control over the transparency of other players, but they can portray market standard by showing its feasibility.

Acorn's research highlights three advantages of blockchain, (1) Uniqueness, (2) Transparency and (3) Programmabillity. Since each carbon credit carries its own characteristics (e.g. issuing date, origin, expiry date). As discussed in section 2.7.6, tokenization allows for the unique identification of carbon credits containing its specific information. For Acorn, this uniqueness of carbon credits on the blockchain can result into variable ratings and values of tokens. Producing an incentive for carbon credit generators to deliver better quality. With respect to transparency, each transaction has an immutable on-chain record. Every state change from creation till retirement can be tracked, as a result double spending can be eliminated from the carbon credit market. The programmability refers to the functionality of smart contracts. Employing smart contracts facilitates automatic transactions based on pre-defined rules. Hence, trading carbon credits on an Acorn blockchain-build platform could be an automated, market-making feature.

5.3.2 Core solution

Acorn made several assumptions on which the design of the blockchain solution is based [Rabobank, 2021]:

- Buyer and certifier require transparent and trustworthy insight in credits and origin
- functionalities of the registry and marketplace all take place on one blockchain platform
- buyers want to have the ability to independently verify that tokens are not double spent

The core of the solution is a blockchain based registry; the record keeping system for unique carbon credits to track their ownership, status and transaction history. An Acorn Token will represent one metric ton of sequestered carbon, which will be automatically generated and issued based on the Acorn protocol. Issuing a token for third parties might follow. The solution contains a digital wallet, allowing users to store, manage and transfer tokens.

The blockchain registry should serve several purposes:

- A registry with publicly available information to uniquely identify offset projects
- A sstem to transparently track "ownership" of CRUs
- Traceability of each credit back to the project from which it originated
- A system to easily check on the status of an offset credit

To support the above mentioned purposes the blockchain ledger should contain information on CRUs: *generating and storing characteristics*, *identifier + link farmer plot data*, *status* and *buyer and transaction details*.

During their research Rabobank found that existing blockchain products do not fit the requirements for Acorn from their standard solution, meaning that the larger part would have to be custom built. Hence, they reached the conclusion that existing products did not fit the requirements. Consecutively, Acorn researched various blockchain technologies in the market that could support their requirements, leading to a longlist of blockchain technology platforms. Acorn used a scoring methodology based on four categorize with approximately 5 characteristics each. Table 5.1 provides an overview of the blockchain solution provided in the white-paper of Acorn. On the left side the main choices discussed in the paper are given, with the corresponding choices made in the middle column.

Table 5.1: Acorn Architecture Overview

Architectural Choices	Choice	Reasoning
Public or private	Public	Transparent transactions & information
Re-use, buy or build	Build own registry	No platforms fitted the requirements
Blockchain technology	Solidity	
Consensus mechanism	Proof-of-Stake	Most energy efficient and reliable
Technology provider	Polygon	See table 5.2
Tokenization	Ethereum token standards	

The choice for the blockchain solution included the use of Polygon, which is a decentralised Ethereum scaling platform. As mentioned, Acorn used an elaborate scoring system to evaluate the different blockchain technology platforms. Additionally, they provided an overview of the benefits and risks associated with Polygon (See table 5.2).

Table 5.2: Risks and Benefits of Polygon from Rabobank [2021]

Benefits of Polygon	**Risks**
Fast Transactions	Less decentralized in nature than Ethereum
Low Transaction Fees	The instability of the Polygon token
Can Be Scalable	Polygon cannot guarantee security as Ethereum
Extremely high Transactions per second	Sidechain validators could commit fraud
Proof of stake chain (Energy Efficient)	Polygon is a platform in development
Interoperable with other EVM-based solutions	The chain can potentially fork
supports Ethereum token standards	
Increasing traction and gaining large community	

Another important consideration for Acorn in choosing the right blockchain platform were the intermediate layers, programming languages like solidity, the acceptance and maturity level and developed standards for tokenization on the specific platform. Apart from the blockchain, Acorn also wants to keep facilitating the web-based marketplace which allows users to upload, publish and sell their minted CRUs. According to the white paper this would be accompanied by a digital wallet which allows users to store, manage and transfer their tokens and poses as a gateway to access the blockchain API.

5.3.3 Model Description & Information Flow Analysis

Figure 5.1 (see next page) is a graphical representation of Acorn's blockchain solution, including the information to be captured on it (either stored on/off the blockchain). The phases for blockchain development got as far as moving to the minimum viable product phase (Personal Communication, Blockchain Expert - Acorn, June 15, 2022). Meaning that Acorn would be able to provide value to their customer with the simplest version of the blockchain-based marketplace. The graphical representation shows that (with how far the research for the blockchain solution has gotten) the data on which a CRU is based, is aggregated by Acorn. After the data would be aggregated and checked, Acorn would put the data on the blockchain and the CRU can be minted. Minting is the process of generating new tokens by authenticating data, creating new blocks and recording the information onto the blockchain. Newly minted CRUs are then added to the circulation to be traded.

Not all new projects are verified by a third-party verifier. Projects for verification are selected at random and the certifier (Plan Vivo) determines the verification party (Personal Communication, Strategy Lead - Acorn, April 22, 2022). Hence, this information is not always required for the creation of a tokenized CRU. Why Acorn's envisioned solution chose to aggregate the data themselves is based on three reasons: (1) The remote sensing needs an adjustment factor for the margin of error in the measurements of the carbon sequestered by the planted trees, this adjustment factor is applied by Acorn (Personal Communication, Strategy Lead - Acorn, June 16, 2022), moreover (2) Acorn, and more specifically Rabobank, wants to maintain a certain level of control over the data and the processes and lastly (3) occasionally the remote sensing data contains mistakes, therefore Acorn wants to make sure that all the data is valid.

On the left side of Figure 5.1, the paper-based flow can be observed, which transfers information from the farmer to the local partner of Acorn. Often, these farmers do not have the resources to set-up a bank account or digitally transfer the documents required [Rabobank Acorn, 2021]. Hence, the local partner collaborates with the farmer to perform the eligibility checks and generate the annual reports. Acorn relies heavily on the local partner to provide the necessary information on farmer details for monitoring and reporting purposed.

Moreover, going over the data that is provided by each party it can be observed that the farmers are responsible for providing information on themselves. Ranging from the farm size, to being able to prove that the land is theirs, coordinates as well as personal information such as phone numbers, names and income.

Proving ownership rights for a farmer of his land can be difficult, since farmers are often not in possession of land permits. On such occasions Acorn's local partners then tries to establish ownership rights via local communities, inquiring by neighbours and demarcating the area step by step. Here, Acorn again leans on the assistance of the local partner.

Zooming in on the link between the local partner and Acorn, it was already established that a local partner is responsible for the data being accrued from the affiliated farmers. The local partner is also responsible for the impact of intervention assessment, where the impact of the specific project is determined for the local community and ecosystem, since carbon offsetting should be based on projects benefiting the environment instead of bringing harm.

This is followed by remote sensing data. Depending on whether Acorn does the remote sensing themselves either they have the data available or the remote sensing party provides the final calculations. To account for model accuracy and pre-planted trees (Trees which were already existent before the intervention) Acorn applies two adjustment factors on the measurements, improving the reliability of the calculations.

The verifier is responsible for verification of the offsetting projects from which Acorn's CRUs originate from. As mentioned, not all programs have to be verified hence when a project needs verification they provide their review to Acorn. Since not all projects have to be verified there is not a standard data field which always has to be ticked.

The last party contributing data to the formation of a CRU is Plan Vivo. As a certifier they provide data such as the issuance data, the status of the CRU, the standard reference used for the generation of the CRU and the reduction type. Without such certification being performed and logged, a credit in general would become less valuable and trustworthy because quality, reliability and validity is not guaranteed.

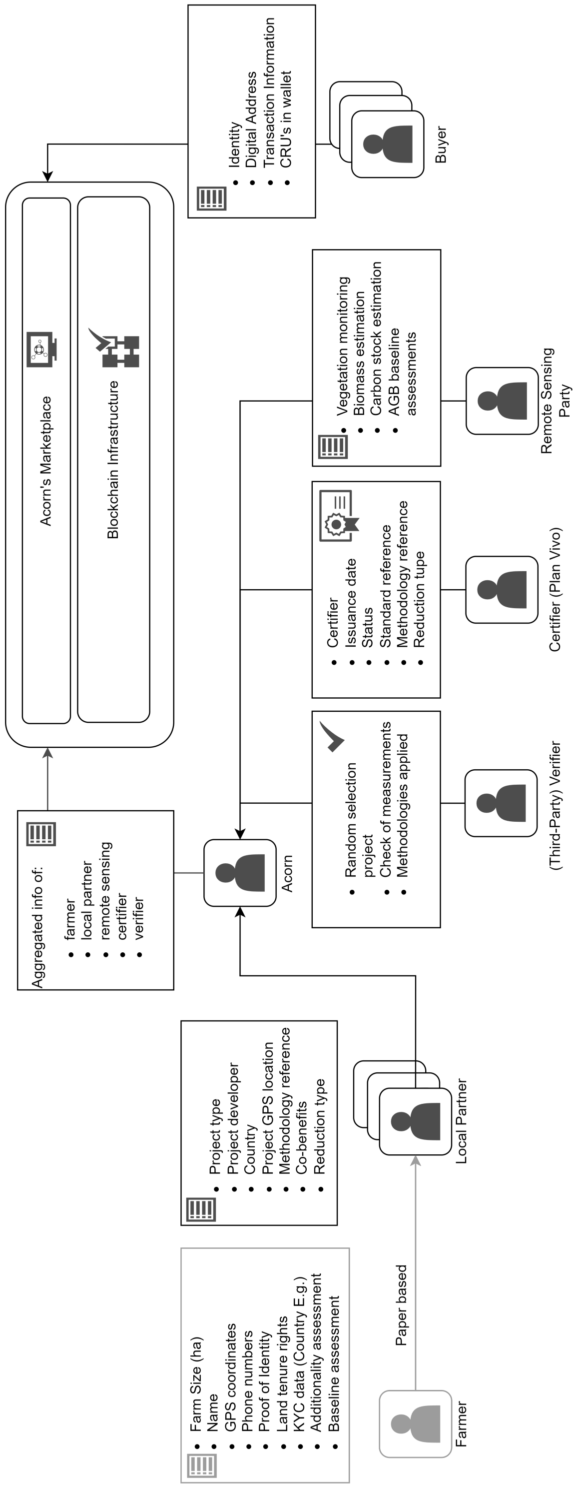

Figure 5.1: Acorn's Blockchain Based Platform Solution

5.3.4 Reasoning for Blockchain Technology

The idea for adopting blockchain was present in the beginning of developing Acorn. When entering the market Acorn encountered multiple challenges, some foreseen and some unforeseen (Personal Communication Founder Acorn, May 28, 2022). One challenge was how to measure carbon sequestration remotely, As Acorn was preparing its business case they explored new technologies to support their processes. The potential of blockchain was recognized and a team from Rabobank's blockchain lab was researching the possibilities for Acorn, external research from a consultancy helped with developing the proof-of-concept [Rabobank, 2021].

The characteristics transparency, security of transactions, reduction in transaction cost, efficiency offered by blockchain technology were compelling. However, after the proof-of-concept had been developed and the white paper on the blockchain solution was (nearly) finished Acorn decided to refrain from further exploring blockchain technology. This decision was based on multiple reasons, one of the main reasons was that Acorn wanted to focus on the supply of the CRU. For the marketplace, demand was accounted for but the supply of the CRUs needed to be increased and establishing new projects takes time. Another main reason was that one of the employees leading the blockchain exploration left the project . Overall, the team felt the market lacked maturity in both quality and stability (Personal Communication Founder Acorn, May 28, 2022). The technology itself also was not perceived as fully ready for such a complex market.

Additionally, from a banking perspective there were reservations with giving away some control to another party which could not be controlled by the bank (Personal Communication Blockchain Expert - Acorn, June 14, 2022). More funding would also need to be allocated to the project and with the aforementioned reservations the blockchain plans were put on hold indefinitely.

5.3.5 Added value/limitations of the blockchain solution & double counting

At this point of the blockchain evaluation only the direct stakeholder context of Acorn is considered, as governance processes and design choices within Acorn have to be clarified first. Subsequently, from this evaluation inferences can be made towards the carbon market.

Benefits

- One benefit of the blockchain is that double selling is completely eliminated by adopting blockchain technology. After the CRUs are tokenized there is no possibility that they are sold twice. Also, because Acorn decided that their CRUs cannot be resold and therefore stay solely in the blockchain registry. Hence, all Acorn CRUs would be accounted for and could not be used by multiple parties.
- Another benefit is that Acorn designed a public blockchain as they aspire to reach market wide transparency. Compared to other banks, this feature would put Acorn at the forefront since they would open up control of the data, whilst a private or consortium blockchain could be more beneficial for Acorn itself.
- As Acorn is part of a bank, sophisticated know your customer processes are in place and they are regulated entities. The endorsement of such a reputable institute reaps the belief that the required processes and infrastructure are in place to facilitate the tokenization of carbon credits [Chow, 2022]
- Negligible benefits are the reduction in transaction cost, although blockchain can reduce the cost of transactions the difference was minimal compared to the current registry (Personal Communication Technology Provider, May 10, 2022).

The benefit of immutability was contested since the information aggregated by Acorn occasionally requires modifications (Personal Communication Technology Provider, May 10, 2022). So despite immutability being desirable, the information flows were not arranged such that they were fault-proof, rendering immutability inconvenient.

Limitations

- **added value** was minimal since the capturing of the data was centralized by Acorn before it was uploaded. Acorn takes on a centralized orchestrated role if one looks at how the governance processes are organized in figure 5.1. This creates a situation in which no essential changes take place, except for the fact that the transactions are more secure on the blockchain. The proposed blockchain solution as is does not add new value compared to a regular registry with respect to transparency, reliability and immutability of provenance data. Only efficiency, security and immutability of transactions would be increased.

  The increased validity and reliability of the data in that sense is lacking since the data is still centralized before it ends up on the blockchain, giving one party operational power which leaves the data exposed to mutations. In this manner, no real transparency throughout the total value chain of the CRU is generated. When the CRU is minted on the blockchain, the CRU is only traceable from prospectively step 'four' in the life cycle. The steps in which the data is generated first by the farmer, the remote sensing party and thirdly to the certifier cannot be traced. Hence, transparency is only provided from the point of when the credit is minted and onward.

- **Scalability** the proposed architecture was also lacking in scalability, which is partly inherent to the characteristics of blockchain as well as the market complexity. To provide a liquid marketplace enough supply has to be generated, to offer stable prices and regulate demand. This would likely require other parties to also sell their credits on the blockchain. As mentioned, Acorn realized CRUs which are one-on-one comparable, other sellers however used different methodologies which could not have been tokenized in the same manner as Acorn's CRUs. This is however more a general market issue and will be discussed more later.

Despite the CRUs not being sold twice, the important variants of double counting are not tackled by the proposed blockchain. It shows that it is able to address double counting within Acorn, this is however not a new revelation since this function was already addressed by the standard registry. Another well organized feature of Acorn is that there CRUs are interchangeable, each CRU has the same face value independent of the project which they originated from. This structure facilitates a convenient and comprehensible marketplace.

Lastly, in their design Acorn chose to integrate not only the distributed ledger technology to maintain its registry, but also built a marketplace by choosing the specific application of blockchain. With this choice, the blockchain-based platform automatically needs to tokenize the carbon credits. Otherwise the credits cannot be traded on the marketplace. This decision is logical since Acorn wants to position itself as project developer and market enabler. However, this choice is accompanied by computationally intensive operations, especially if other parties are on-boarded. Opting to use blockchain solely for its registry functionalities is more convenient as it removes the difficulty of credit tokenization. Be that as it may, the platform then cannot function as a blockchain-based marketplace. As such, the desired end-to-end transparency, traceability and reliability in the supply chain is lost.

5.4 PROPOSED IMPROVEMENTS BLOCKCHAIN-BASED PLATFORM

The improvements proposed in this section are for the controlled environment of Acorn's blockchain platform. At this stage extensibility, connectivity, inclusion and the global market dynamics are not considered to their full extend. Looking at figure 5.2 one can see the envisioned blockchain with the information flows to the blockchain from each stakeholder. The figure depicts what source data flows to different actors and who will be benefiting from this information.

The added value of this network typology configuration for the blockchain solution is the decentralized information flows, on project information, verification and certification. Untangling these information streams whilst not offering one party sole control. Organizing the information flows as in figure 6.2 would increase information transparency, immutability and data security.

The minting of CRUs, whitelisting and identity management are all captured in the smart contracts. The required transparency of anyone being able to see the transactions, provenance and stored data is facilitated by the public blockchain. Some form of verification is required as well, since only parties with honest intentions should be able to buy removals. Hence, the blockchain should also feature identity management in its smart contracts.

The smart contracts facilitating the tokenization need to be constructed such that it follows the sequence of steps of data generation for the minting of a CRU. The minting starts of with the farmer, uploading the necessary data, followed by the local partner, remote sensing party and lastly Acorn for the margin errors. After the data on the project has been collected the certifier and verifier come into play. The certifier, Plan Vivo, needs to review the data alongside its standards and if in accordance provides it signature towards the CRU. Moreover, Plan Vivo decides which projects are subjected to verification. Remember that verification happens at random and is performed once every three years. Hence, Plan Vivo will have to indicate per CRU if verification will take place. If so, the minting shall be completed after the verifier has been able to view the measurements and methodologies applied for the project, determine whether this is in accordance and provide it's decree on the validity of the project. Otherwise, the minting is finalised after Plan Vivo has given its signature.

Issues that remain for the blockchain if Acorn would develop the blockchain remain on the supply side, scalability, know your customer processes and risk assurances for the bank. An overview is given in Table 8.1.

Table 5.3: Remaining Issues for Acorn in Proposed Blockchain-Based Platform

Governance Requirements	Remaining Issues	Context
Constitutional Rights	Identity Management	Can it be feasible to perform the required KYC checks?
	Sufficient Supply	How and which suppliers should be joined on the paltform?
Collective Choice Rights	Risk	What happens if the blockchain fails?
Operational Rights	Accessibility	How can and should access to the platform for farmers be arranged?
	Goverance	How to ensure that there is no room for human error?

For the marketplace to perform like a marketplace, enough liquidity has to be in place. However it is uncertain whether this liquidity can be provided solely by Acorn. Allowing other suppliers onto the blockchain requires some exhaustive know your customer processes since all linked parties will have to be screened via Rabobank's processes. This could prove to be unfeasible [Sazandrishvili, 2020], however if organized in a different manner the added value of decentralization in minting the carbon credit is lost. Secondly, the smart contracts and tokenization would be defined solely for removals. Other types of carbon credits could not yet be admitted on the blockchain because the correct tokenization for other types has not been designed yet.

A more practical concern is for Acorn to explore how to get farmers to upload their data on the blockchain correctly. Either this process would have to be supported for example by the local partners, they can demonstrate to the farmer how to do so and allow the use of their own hardware as farmers generally do not have access to this. Another solution could be that the farmers would have to receive some budget or hardware to set-up the necessary infrastructure. Only organizing this process alone could prove to be increasingly difficult, impeding the feasibility of such blockchain platform designs.

A key takeaway from Acorns processes is the remote sensing capabilities that are based on GPS polygons. Despite programs and projects using different methodologies to quantify sequestered carbon, the location on which it is constant. The GPS polygons allow for easy verification of where and by whom a removal took place, providing unequivocal ownership rights of the corresponding credits. If the platform would be opened up to other project developers in agroforestation, this property should be assigned to each project. Overall, easing the identification of double counting by other parties.

Lastly, a concern for the blockchain-based platform is that all uploaded data needs to be accurate, once the CRU is minted the data becomes immutable. This requires sufficient checks to be in place for data accuracy for each party in the supply chain supposed to upload data.

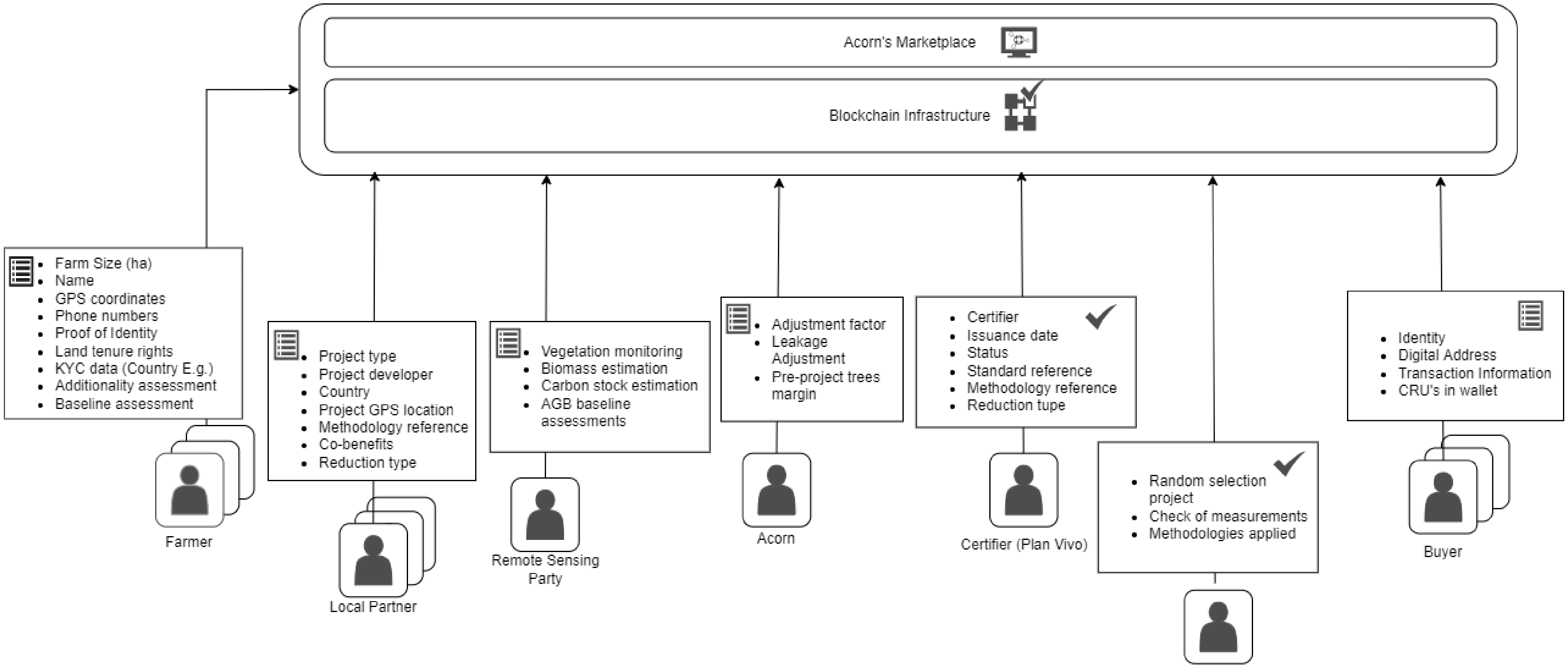

Figure 5.2: Blockchain Architecture Acorn 'Ideal' Solution

5.5 CONCLUSIONS CHAPTER 5

Chapter 2 set out the fundamental characteristics of blockchain technology. By doing so, it justified the selection of blockchain technology for a digital environment that can turn into a blockchain-based system for the registering, accounting and trading of carbon credits to explore if blockchain can aid in reducing the quality issue of double counting. The suitability of blockchain is also demonstrated by the document analysis of Acorn's in-house documents as well as the extant literature [Agrawal et al., 2021; Azzi et al., 2019; Kilkenny and Robinson, 2018; Franke et al., 2020; Mandaroux et al., 2021; Francisco and Swanson, 2018; Sazandrishvili, 2020; Valeonti et al., 2021]. The sections on tokenization and blockchain configurations deepened the reader's understanding enabling them to better understand the evaluation of the blockchain solution in chapter 6. This chapter led to the answering of the second sub-question: *What are the key features, benefits and limitations of blockchain architecture with respect to the prevention of double counting?*

Furthermore, the chapter dived deeper into Acorn's blockchain solution and evaluated the choices made, corresponding governance requirements and explored possible improvements. This resulted in a proposal for an improved blockchain solution for Acorn and answered sub-question 3: *What are the benefits and limitations of Acorn's blockchain solution which can be identified by applying the framework of van Engelenburg?*

The main limitation of Acorn's blockchain solution was the centralization of data by Acorn before tokenizing the carbon credit. Considerations of Acorn for this choice are clear, (1) ensuring data accuracy, (2) maintaining partial control, and (3) convenience. Despite integer intentions, accruing all data to one party who has the ability to change the data in an untraceable manner directly opposes the basic notion of blockchain technology. Moreover, the strategy for scaling the solution was not thoroughly established by Acorn. In the ideal setting, Acorn would be able to easily onboard other trusted developers onto their platform, for both supply and double counting purposes. Problematically, in the current market and lack of uniform definitions of carbon credits this is difficult.

Conclusively, the case of Acorn shows that there are definite benefits offered by a blockchain-based platform. The choice of hosting the registry and the marketplace on the same platform adds a layer of complexity since it requires a CRU to be tokenized. Looking ahead, further development to govern the information flows and reach the desired balance between centralization and decentralization of information is required.

6 INTEGRATING THE SOCIAL AND TECHNICAL DIMENSION

This chapter entails the integration of the findings from the social dimension from Chapter 4 with the technical benefits and limitations identified in Chapter 5. The objective of this chapter is to identify the principal trade-offs, considerations and requirements that could surface in the design process of blockchain-based systems situated in the context of the VCM. Insights into the challenges experienced from different stakeholder perspectives, combined with global market dynamics and technical opportunities are of importance to facilitate the identification of such trade-offs.

These insights are gained by investigating the perceptions of stakeholders involved in both the business side of Acorn as well as blockchain experts involved in the development of its blockchain solution. Additionally, the views of multiple technology providers and market strategy leads broaden the view on the applicability of blockchain for double counting and provide the relevance for the global carbon market. By doing so, the 4th sub-question, *How does the Acorn solution contribute to addressing the wider problem of double counting, adopting the wider stakeholder perspective and what are additional aspects that remain to be addressed to achieve an industry solution?* is answered.

The first trade-off that materialized is the renowned question of centralization versus decentralization in information systems. Part of this trade-off is the market dynamics, gradually moving towards the adoption of meta-registries. Meta-registries could prevent double counting as they provide a single source of truth, however a technical limitation of blockchain technology is that it offers limited interoperability of carbon credits between different blockchains.

The second principal trade-off is the option to employ tokenization to leverage the benefits of end-to-end traceability and automated trading of carbon credits versus the adoption simpler blockchain solutions to ensure audit traceability and reduce technical complexity.

The findings provided insights on low-level design choices influenced by global market dynamics. They illustrating how and what interdependencies can impact the applicability of blockchain-based systems. From the in-depth case study, several requirements materialized. The most important requirements considered the scalability of the blockchain solution, the data integrity provided the blockchain-based system and credit elements like durability and maturity.

6.1 INTEGRATING THE SOCIAL AND TECHNICAL DIMENSION

Throughout the thesis the socio-technical context of double counting has been the common tread. Chapter 5 delineated both the stakeholder context, identifying the actors involved in carbon offsetting and carbon markets, and the issue of double counting. Chapter 6 investigated the suitability of blockchain for carbon markets, discussed Acorn's proposed blockchain-based platform and presented improvements to the design. This chapter integrates both the stakeholder domain and the technical domain, through the mapping of themes emergent from the analysis of the case study. During the delineation of double counting several issues presented itself: (1) transparency in emission reporting of companies and governments as well as in carbon offsetting projects and their supply chains, (2) market-wide stakeholder alignment on both standards and corresponding definitions, (3) traceability of the carbon credits, (4) improved security and decreased room for human error, and (5) unequivocal ownership.

In the previous decade the VCM was often referred to as the 'wild west' [Dhanda and Murphy, 2011; Nerlich and Koteyko, 2010; Blum, 2020], since then stronger standardization in the market led to higher trust. However, it can be argued that standardization is as relevant now as it was then, especially with the blockchain providers eager to pioneer their blockchain applications in the carbon market. One of the propositions in the thesis is that standardization is not easily enforced due to the many interrelations.

To facilitate the integration of the social and technical dimension the thesis zooms out to consider the wider context of the carbon markets. The analyses showed that this proposition is confirmed by the empirical context. Figure 6.1 (see next page) depicts a severe simplification of the network resulting from the case study. As the network is far too big and crowded to illustrate both the main themes as well as the entangled nature of the themes and issues, an abstracted version is presented. The full network can be found in Appendix E (the coloring of the scheme matched to the full network). Figure 6.1 captures the main themes which are depicted in a hierarchical manner, to emphasize the overarching themes. It does not imply importance of the themes or any other statistics.

At the bottom in red, the categorization of global challenges is depicted to illustrate how each theme corresponds to the general issues. The dotted lines indicate associated relationships and the full lines depict relations between concepts and/or themes. The actor theme and its relations is purposely left out to preserve some comprehensibility of the scheme. Since the stakeholder dimension has been thoroughly discussed it is assumed that enough knowledge has been gained to keep in mind the rational.

The main themes that emerged from the analysis are standardization, market clarity, quality, transparency, applications of blockchain technology, transparency, trust, marketplace, stakeholder alignment, data (standards) and standardization. These themes should be seen as all-encompassing labels for all elements grouped under a specific theme. Figure 6.1 is introduced to convey the chaotic structure of identified themes, the multifold of factors influencing specific concepts in a disordered manner and the position of solutions compared to the challenges. The following sections will discuss the main themes depicted in 6.1 and their implications for the global carbon market.

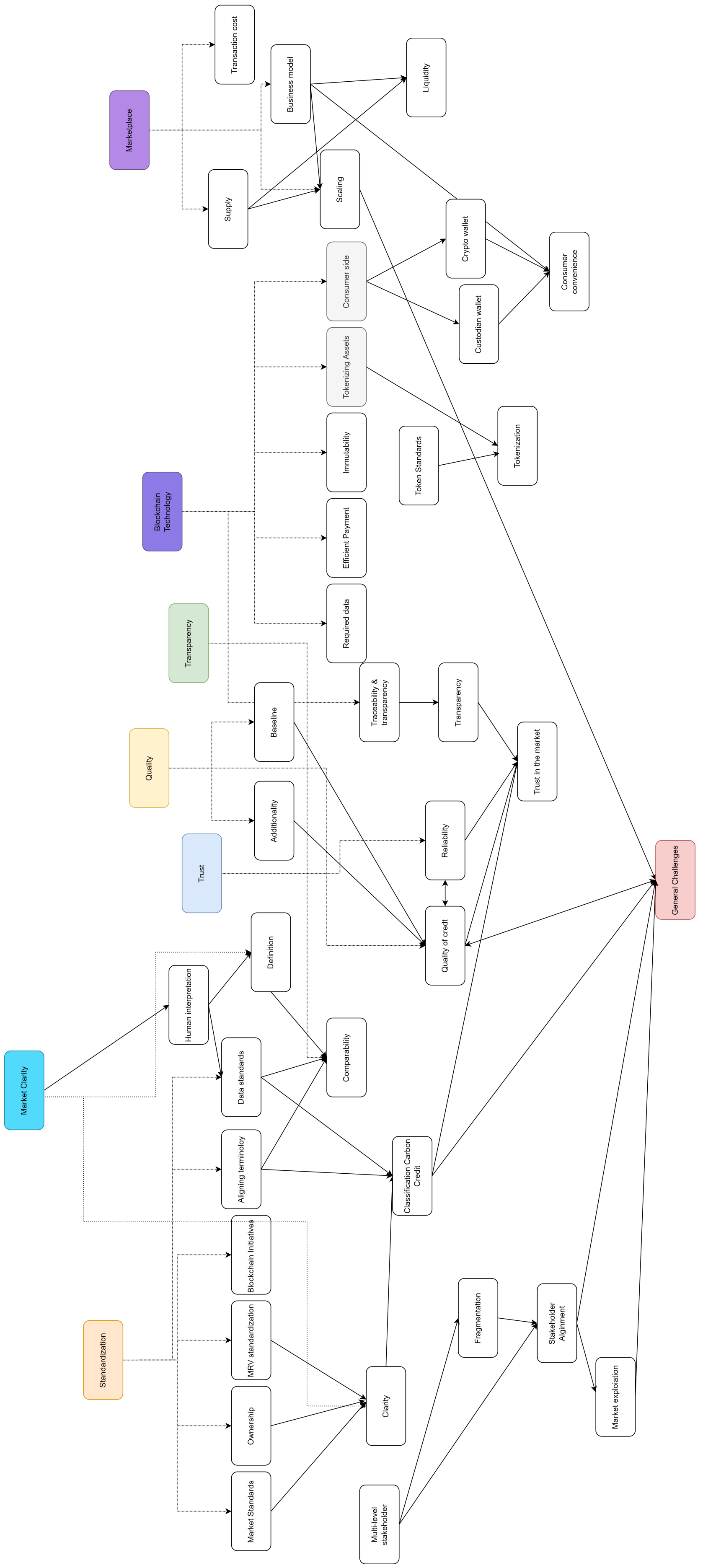

Figure 6.1: Simplified scheme of umbrella themes derived from empirical findings

6.2 STANDARDIZATION

During the interviews the theme of standardization kept resurfacing. The analyses exposed that the concept of standardisation is comprised of composition of multiple sub-concepts, namely; how to define a carbon credit with respect to asset tokenization, corresponding market clarity on what can and cannot be sold in the VCM and lastly, general monitoring, reporting and verification standards. In the sub-sections below these concepts and their interrelations are discussed.

6.2.1 Defining a carbon credit

Many technology providers are working on blockchain applications for tokenizing carbon credits. They see potential in shifting carbon credits onto blockchain to improve the market as well as value propositions in this for their businesses. Throughout the analysis it became clear there are two points of view among technology providers, (1) either standardization and defining what a 'carbon credit' is is up to the market and (2) blockchain initiatives should collaborate to work on a standard for tokenization together to prevent further fragmentation.

Table 6.1: Quotations on definition of carbon credits

Theme	Quote	Individual
Definition carbon credit	*"what I like to emphasize is that blockchain is used for efficient settlement of transactions for the execution of assets and settlement of transactions. And so anything beyond that comes as our human interpretation of let's say, these assets, and then how do we define these assets? So it's not a problem that is inherent to the blockchain technology."*	Blockchain Expert Quantoz
	"like it will always will never be someone other than the regulator who will come and tell you that this is the format that you need to follow. There are lots of NGOs working on it. They're working on trying to defining that say, what does it mean to what does it mean to create a standard for carbon offsets."	Blockchain Expert Quantoz
	"It's a bit like you can type into Google right now: Create PDF, and you could get a tool which allows you to turn a Word document into a PDF, that tool is basically what we do so we don't control what's written on the Word documents."	Blockchain Expert Toucan

The main issue underlying these point of views, is the need for a singular understanding of a carbon credit, which goes hand in hand with the misclassification of carbon credits with respect to removals or reductions. Companies use these interchangeably when reporting their emissions [Ascui and Lovell, 2011].

6.2.2 Classifying a carbon credit

They claim themselves as being 'carbon negative', however one cannot truly call themselves carbon negative when they only purchase carbon reductions which are based on avoiding carbon emissions instead of removing carbon from the atmosphere. If the emissions have not been overly compensated by reductions the term carbon negative is incorrect. Despite such nuances seeming small, they are important for the functioning of the carbon market [Greenhouse Gas Management Institute and Stockholm Environment Institute, 2020].

A distinction should therefore be in place showing the difference between a corporation being 'climate conscious' or 'carbon negative'. Currently, these discrepancies confuse the landscape of disclosing which increases the difficulty of emissions reporting and addressing double counting [Ascui and Lovell, 2011; Schneider et al., 2014; Shrimali, 2021].

Table 6.2: Quotations Classifying a carbon credit

Theme	Quote	Individual
Market Clarity	*"From that point of view, but claim is not the same, you can say as Microsoft, we're climate neutral, you can say, okay, we support the climate. And that's why we used avoidance credits, which is a good thing. But that clarity should be established in the market."*	Founder Acorn
	"So can a reduction be sold in the same name as a removal? I think there should be a difference. And also the claims that can be made are fully aligned."	Founder Acorn
	"I think that these mainly in strict criteria are what can be sold in the voluntary carbon markets and what cannot be sold in the voluntary carbon markets."	Founder Acorn

6.2.3 Link Between Compliance Market & VCM

Part of the classification mentioned above relates to the link between the Compliance & Voluntary Carbon Market. Currently, the link between both markets is ambiguous [Blum, 2020; Lang et al., 2019; Schneider et al., 2020]. Carbon credits from the compliance market can be sold in the VCM, but not the other way around. Yet, Standards in the VCM like CAR and Var certify credits from the compliance market. Definite clarity has to be established on how these markets either exist separate or linked to each-other. Half ties and semi-interchangeable credits only add to the complex nature of the carbon markets.

Table 6.3: Quotations Link between Compliance & Voluntary Carbon Market

Theme	Quote	Individual
Link between Compliance & VCM	*"And they have a complete different agenda. They want to have those governments to sustain their forests which is a great thing, but not in the voluntary carbon market, because it doesn't work from a carbon accounting perspective."*	Strategy lead Acorn
	"You see some, they said okay, the voluntary carbon markets is out of scope towards 27, you see a lot happening. They say those are still the results of COP 26. That should go clarity how the voluntary carbon market links to the compliance market, otherwise you cannot sustain a VC market."	Founder Acorn
	"But also for those registries, I think the solution is not it building a new blockchain or the challenges in building the clarity in the market. And that has nothing to do with Blockchain."	Founder Acorn

Defining the link between the compliance market and VCM, will clarify whether a voluntary credit can be used for NDC's or not and unequivocally determine if a project is in agreement with a local government. Then ownership can be established, in which it is determined that a voluntary project is reaping carbon credits and these will not be included in a governments' NDC.

6.2.4 Monitoring, Reporting & Verification

Part of the quality issues underlying a carbon credit can be attributed to questionable third-party performing the monitoring & verification. This issue has already been identified throughout the literature [Blum, 2020; López-Vallejo, 2022; Reuss et al., 2022; Schneider et al., 2014] but is emphasized in again in the empirical analysis. As the methodologies differ per standard, monitoring and validation purposes are reliant on the methodologies of the standards used and differ continuously. Projects get verified by individuals who never leave they desk, and generally just accept what is presented.

Table 6.4: Quotations on Monitoring, Reporting Verification

Theme	Quote	Individual
Monitoring & Verification	*"then get monitored by questionable third parties, they get verified by people who never even leave their desks, they just accept the reports that are given to them."*	Blockchain Expert Toucan
	"But they will be able to finance projects from the early stage, that the provenance of the credits as they move through the cycle, from the sort of monitoring, reporting, verification and issuance to being traded and eventually being retired, that entire provenance will stay within the metadata of the credit"	Blockchain Expert Toucan
	"The verification process should result in the creation of a high-quality digital asset, a credit token, whose value can easily be determined and quickly be compared with other tokens of the same type. However, all the data needed to verify the integrity and value of the token should not all reside within the token itself but be available in other data constructs"	IWA report
	"And on top of this, there's a bureaucracy layer of admin, where people do a lot of manual entry data, there's a huge amount of room for human error. It's very slow. It's done via emails and spreadsheets. So all these things, enable bad actors."	Blockchain Expert Toucan
	"I think it should still be like central databases somehow whether that's a registry linked to this central database via blockchain or it is just with an API, or just by sending an email monthly doesn't matter so much."	Founder Acorn

An interesting observation is that the perceived possibilities for blockchain with respect to MRV can differ. The perspective from the project developers side is that everything is easily arranged in the status quo. A central database can be managed by sending a monthly email, in accordance with this perception the added value of blockchain is severely doubted. The opposite view from a technology provider's perspective is that blockchain can bring the needed professionally, immutability and security in the processes of creating, reporting and monitoring carbon credits.

6.3 STAKEHOLDER ALIGNMENT

Again in stakeholder alignment two trends can be identified: *(1) the coordination of multiple parties trying to define standards related to blockchain applications and, (2) global stakeholder alignment related to mitigation projects aligning and the alignment on policies.* These trends are captured in Table 6.5.

Standardization and governing bodies are interested in blockchain technology to improve quality, immutability and fast and secure transactions. To begin with, the Inter Work Alliance, a platform-neutral, non-profit organization, drafted a report to establish standards for tokenization, contractual extensions, workflows, and analytics for creating a standards-based ecological market [InterWork Alliance, nd].

Essentially, multi-party digital interchanges require a trusted, agreed-to representation of value, correlating contractual agreements. A substantial part of the market actors ranging from technology providers, businesses [Chow, 2022] to standardization bodies [Adams et al., 2021; InterWork Alliance, nd] seem convinced that tokenization on blockchain can facilitate this best.

For example, a large collection of technology providers is working together to define the properties for tokenizing a carbon credit together to avoid further fragmentation of the market. Another example is a group of seven banks working to establish their own blockchain-based carbon credit platform [Chow, 2022].

At present, many parties are working on the tokenization of carbon credits to be the first one to crack the market despite some forms of collaboration being established. Once again, the lack of a strong governance body and corresponding rules & regulations allows for the VCM to be further fragmented and possibly devalued, if multiple blockchains harboring carbon credits arise from the race to tokenize carbon credits.

Table 6.5: Quotations on stakeholder alignment

Theme	Quotations	Individual
Stakeholder Alignment	*" I think a high-level multilateral agreement on governmental level, so I think it's the UNFCCC that has to align on how the voluntary carbon market links to national guidelines or schemes"*	Founder Acorn
	"And basically, there are multiple efforts that have been made by multiple agencies to try to define a common standard to use in order to identify these tokens."	Technology provider Quantoz
	"That also requires some kind of coordination between different registries, of course. Because yes, we can show on our registry that it has indeed not been sold twice. But hey, what if you put it on some other registry that let's them do it again?"	Blockchain Expert 1 Acorn
	"I bet on 40 startups are working together to solve this quicker than seven banks, basically, who all want ultimately to control the data. So the standardization thing is happening. "	Technology provider Toucan

From a global perspective, multi-party digital interchanges require a trusted, agreed-to representation of value, and correlating contractual agreements [InterWork Alliance, nd]. Unfortunately, technological disparity across platforms creates roadblocks that inhibit the level of interoperability necessary for web-scale adoption. There needs to be a unified approach where all parties work together to build out an ecosystem that is global. Other initiatives, also aiming to tackle climate change are operating from a different perspective with their own agendas. For example the UN environmental program to sustain forests. These are not necessarily hindering the VCM, yet the agendas are not aligned and therefore create some form of fragmentation because it for example clashes with current accounting frameworks. Overall, adding to the difficulty of stakeholder alignment in the global carbon market.

6.4 MARKET EXPLOITATION

A recurring theme in the analysis is market exploitation. Due to the lack of regulations actors in the are exposed to several forms of exploitation. The first concern is that the technology providers entered the market for their personal gain, with no regard for what the market is trying to accomplish, namely climate change mitigation.

Another concern is that unforeseen externalities accompany Scope 3 awareness. Food companies are seeing tremendous CO2 emissions in their scope 3 (Personal Communication Founder & Strategy Lead Acorn , June, 2022). They feel pressure to reduce or compensate these emissions, which theoretically should be a positive reaction. In practice, companies pressure farmers and similar actors from their upstream supply chains to assign sequestered carbon (part of voluntary projects) as part of the sourcing of the product. To illustrate, a coffee company sources it's coffee beans in Columbia and requires the farmer to appropriate the trees on its farm to the sustainable sourcing of the coffee beans without offering compensation. There is a lack of guidance ensuring fair treatment of farmers who are accounted for as a scope three supplier. If farmers are considered in a company's scope 3, they cannot participate in the Voluntary Carbon Market and receive payments for their ecosystem services. Through such activities the transparency and legitimacy of the market continue to be challenged. Once more negatively impacting consumer trust.

6.5 BLOCKCHAIN TECHNOLOGY & MARKET DYNAMICS

Bringing the innovative technology into the picture, multiple issues rose to the surface from both the technology providers as well as Acorn's blockchain experts and strategy lead. Defining a carbon credit was previously identified as a challenge in 6.2.1, this challenge is extended by the technical context of defining token properties. Next, the effects blockchain initiatives can have on the VCM are discussed followed by limitations of blockchain technology.

6.5.1 Defining Token Properties & Human Interpretation

The concept of defining the properties of a carbon credit was stretched in the interviews with technology providers, illustrated in Table 6.6. Without an understanding of what a carbon credit really is, it is increasingly difficult to define the right properties constructing a carbon credit. As mentioned, several parties are trying to define standard properties for tokenization standards. The Inter Work Alliance, drafted a report to establish standards for tokenization among other things. Despite the report setting the stage, several properties could be interpreted differently and remained ambiguous. The core carbon principles developed by the InterWork Alliance [nd] are not clearly measurable. The report states that several previously undefined principles are quantified, but established methods on how these properties should be quantified, among what axis and over which time frame continue to lack.

Table 6.6: Quotations on definition of token properties

Theme	Quote	Individual
Definition token properties	*"So how do you define a token? And basically, there are multiple efforts that have been made by multiple agencies to try to define a common standard to use in order to identify these tokens."*	Blockchain Expert Quantoz
	"Well, at the moment, a credit only needs to have at the highest level, it needs to have the project number methodology and vintage, okay. But that's in the that's just replicating the traditional way"	Blockchain Expert Toucan

6.5.2 Effects of Blockchain-Based Market Initiatives

Another theme related to the relative volatility of the VCM, that came forward was the possible effect of blockchain-based initiatives. A brief example of such devaluation was already given by Toucan's initial solution. They aimed to improve the disorganized, archaic and sluggish VCM as well as accelerate carbon offsetting by pushing carbon credits onto a blockchain-based platform [Chow, 2022]. Although harboring good intentions, the initiative failed due to underlying credit quality issues of credits that were put on the blockchain by secondary parties and due to reviving bad-credits off-chain to new on-chain credits. Prices began to sway, causing panic among traditional carbon credit issuers and buyers [Chow, 2022].

Verra, one of the leading standards and issuer of carbon credits withdrew from the initiative and banned the conversion of retired Verra credits into tokens. For the future Verra is considering to work with bank-led initiatives only using live tokens [Chow, 2022]. This events surrounding this initiative once again corroborate the argument that tokenization of carbon credits can potentially drastically impact the VCM, but if the social-context is not completely aligned with the technical constructs issues quickly arise. This event illustrated the volatility of the VCM and the importance of quality and reliability once more.

6.5.3 Blockchain Limitations

One limitation of blockchain technology is that bridging multiple registries to create a meta-registry is not directly solving double counting and fragmentation issues. Singular blockchains can be viewed as closed-loop environments and without the exact same credit components, the credits cannot be transferred from one blockchain to the other even when bridged [Valeonti et al., 2021]. If and only if one definition is used for a carbon credit and its tokenized in the same manner with comparable underlying value a meta-registry can be feasible to prevent double counting (See Table 6.7).

Another limitation is the shift from the current situation to the blockchain. The use case from Toucan showed that transferring live credits from registries onto the blockchain can result in quality issues and price fluctuations [Chow, 2022]. Additionally, the most value of tokenizing carbon credits is reaped from decentralized data provision as accumulation of the data by a singular entity does not bring the necessary level of enhanced security, immutability or quality. Therefore, transferring such credits is only partially beneficial and if done wrongly can negatively impact the market. That leaves the question of whether only new credits should be put on the blockchain. If only new credits are allowed and directly minted on the blockchain. This would leave the market open to a very slow transformation from off-chain to on-chain, which affects liquidity and could possibly add to the fragmentation. On the other hand allowing current credits to be transferred could lead to discrepancies, sustain low quality credits to circulate once more overall decreasing market trust and quality [Chow, 2022].

Table 6.7: Quotations on blockchain limitations and technical reservations

Theme	Quotations	Individual
Blockchain limitations	*"So here, the problem is, let's say when people speak about interoperability is that they imagine that say that the token lives on this blockchain can somehow transfer to another but that's impossible. Impossible."*	Blockchain Expert Quantoz
	"Millons of carbon credits started arriving on chain thanks to a campaign from another crypto environmental group called KlimaDao. But many of them were attached to low-quality, long-dormant projects that didn't actually improve the environment."	Article Chow
	"If carbon-offset prices keep fluctuating as widely as some of the crypto assets have been fluctuating, that makes it difficult...to plan and develop carbon-reduction projects"	Article Chow

6.6 MARKETPLACE

The term marketplace is often used to refer to blockchain-based platforms which facilitate the trading of carbon credits. The case studied also introduced a registry and marketplace combined onto one platform. The lifecycle of a carbon credit can hypothetically be split into two phases: (1) the minting of the credit and (2) the trading of the credit. Both phases require different technical features. When the trading of credits is facilitated via blockchain-based applications, additional consumer considerations become important. These consumer considerations are discussed in the following two paragraphs supported by quotes from the case study in Table 6.8.

6.6.1 Trustworthiness and Ease of Access

For the consumer two trends are observed. Firstly, the trust and reliability of the market which has been discussed throughout the thesis. The buyer is interested in two things, the first is trustworthiness that the removal behind a credit is real,and if something turns out to be wrong they know where to turn. There should be a good mechanisms in place, in the form of a trusted partner, behind these carbon removals. As a seller what you promised, what you deliver and how reliable you are, should align.

Table 6.8: Quotations on consumer convenience

Theme	Quotations	Individual
Consumer considerations	*"For the buyer I think two things are really important. One is the trustworthiness that a credit is true, it is what we promised. Secondly, that for instance if something goes wrong, they know where to go. Such that there is a trusted partner behind a CRU"*	Founder Acorn
	"We really looked into custodian solutions for example, such that a buyer does not have to make his own wallet and does not have to hold his own cryptocurrency. So a convenient use of credits were very important for the buyer perspective"	Blockchain Expert 2 Acorn
	"To do that, to think from a buyer's perspective, we really looked at convenience, given the fact that blockchain isn't as established. Especially in corporate environments"	Founder Acorn

The second trend is about consumer convenience, as the VCM is contemporary and complex it can be hard for buyers to navigate through. During the analysis it became apparent that certain tokenization of carbon credits did not have the desired effects intended by the Toucan, when they first digitized the carbon certificates. Due to the intangible nature of carbon credits, consumers did not understand the good that they were buying. They expected the tokenized carbon credits to act like other cryptocurrencies. Not surprisingly however, the prices did not behave like the other cryptocurrencies and the consumers eventually realized that they were buying low quality credits. Soon after prices began to drop, investments were lost and the market destabilized.

Hence, in light of blockchain-based applications, solutions should ease buyer convenience. Such applications should facilitate a comprehensible marketplace for carbon credits, providing easy access to the market with intuitive interfaces and being transparent on the product being sold.

6.6.2 Supply & Liquidity

Sufficient liquidity of credits is seen as the principal requirement for an effective marketplace. Without liquidity, the price of the credits becomes less stable. As demand is expected to increase, prices will rise significantly if supply rises. This impacts consumer behavior and can reduce overall belief in the market. Generally, a liquid market is perceived as healthier as they equate more stability and less risk with respect to long-term strategies. The analysis showed that liquidity is equally important in the VCM compared to other financial markets.

Table 6.9: Quotations on supply and liquidity

Theme	**Quotation**	**Individual**
Supply & Liquidity	*"So we put all those credits that have similar features together, so that there's deeper liquidity"*	Blockchain Expert Toucan
	"It should also sell third party credits. So we made a strategy, I really still stand by that strategy, that you need to have a liquid marketplace, therefore, you need a lot of buyers and a lot of sellers."	Blockchain Expert Acorn 2
	"Only that, of course, requires a liquid market, because otherwise it really makes no sense to build a marketplace and well, we are not there yet in the market."	Blockchain Expert Acorn 1

Toucan for example pools credits whom have a similar vintage and particular methodology together because these credits have roughly the same price, to create deeper liquidity. Acorn established liquidity by creating universal CRUs originating from different farmers and corresponding projects, but all sold for the same face value. Moreover, one of the reasons for not pursuing blockchain was the fact that they wanted to generate more supply beforehand.

One of the risks regarding liquidity as shown in the case of Toucan, is that the supply needs to be credible.

Bringing old, (and unknowingly) bad credits into a new environment and reviving them, can lead to quality issues. Acorn ensures this through creating their own supply and generating ex-post credits. Considering meta-registries like Toucan's, it becomes clear that determining what credits can be put on the blockchain is crucial. Hence, just linking several blockchains or blindly transferring carbon credits from off-chain to on-chain can result in unwanted side-effects.

In the Acorn case, the reselling of CRUs were not allowed. This was done to ensure that all profits were received by the farmer instead of speculators. However, the possibility of reselling carbon credits attracts investments. It is more attractive for investors to invest in projects from which credits can be resold as inspectors expect the credits to gain value over time, which would increase profits when credits are resold. This boils down to speculation on the possible increase of value of the carbon credits. On the one hand this attracts investors to invest in offset projects which is desirable, on the other hand it denies for example the farmers to profit from the increase in prises and it undermines the goal of the mitigation activities.

6.7 CENTRALIZATION VERSUS DECENTRALIZATION

The analysis showed that all case study participants belief that to definitively prevent double counting and simultaneously reach market-wide standardization, some form of centralization is desirable. This is desirable because as long as credits are hosted by different parties on different platforms and reported via different mechanisms, double counting can never be completely prevented in a global setting.

Table 6.10: Quotations Centralization vs. Decentralization

Theme	Quote	Individual
Centralization vs. Decentralization	*"I think it's, it should be like, still, like central databases somehow, whether that's a registry linked to this central database via blockchain. Or it is just with an API, or just by sending an email monthly. Doesn't matter so much."*	Founder Acorn
	"I think I think they have like if I think they either need like a like a blockchain solution, or you need like one central Institute's who were all government greatest in the world needs to like, I don't know, adhere to or be registered."	Blockchain Expert 2 Acorn
	"That also requires some kind of coordination, of course, between different registries. Because yes, we can show on our registry that it has indeed not been sold twice. But hey, what if you put it on some other registry that let them do it again?"	Blockchain Expert 2 Acorn
	"So yes, eventually you will come to a kind of single source of truth. But yes, you do need that, as long as it is clear where all that data comes from, then it does not matter that you have to go to a place."	Blockchain Expert 1 Acorn
	"So let's say the interoperability would still happen that same on centralized entity. So like, the interoperability would be that Suzanne owns a, an address on Ethereum and an address on Algorand. And she would act as the bridge between those two parties."	Technology Provider Quantoz

One of the pillars of blockchain is its decentralized nature, that removes the need for an untrusted third party to facilitate transactions between two entities. The analysis demonstrated that, for the VCM a certain level of centralization is desirable to streamline accounting standards, project methodologies, stakeholder interests and token properties. Moreover, without some form of a centralized database it is impossible to eliminate double counting. It is worth questioning whether the potential benefits of blockchain weigh against the difficulties of establishing adequate tokenization. The same notion was found by van Engelenburg et al. [2020], whom argued that the distributed nature of blockchain combined with the complexities of business & governance information sharing rarely leads to simple centralised governance arrangements. The findings from the Acorn case confirm this argument, as its a different case situated in a different domain exhibiting the same behavior.

On a similar note, in the logistics case studied by Segers et al. [2019], it was argued that high degree of decentralization as advocated by blockchain is not always needed, and in the case of customs a reliable audit trail is more important than having a highly decentralized system. The same argumentation should be considered for the carbon market. Minting and tokenizing carbon credits on a blockchain-based platform realise a very reliable audit trail, from the creation of a credit until its retirement. Simultaneously, it facilitates the transfers of credits across jurisdictional boundaries in an efficient manner. Automatizing the verification of credit transfers increases the end-to-end reliability of the audit trail. This is important as it strengthens the property rights of carbon credits. Without the tokenization of carbon credits, the blockchain cannot facilitate transactions between parties. Yet, facilitating both the minting and tokenizing of carbon credits on the blockchain is resource intensive. The tokenization would have to be organized such that many different suppliers can be on-boarded.

Essentially, multiplying the business process model illustrated for Acorn (See Figure C.1) many times. Adding thorough Know Your Customer processes to this model quickly becomes time and resource consuming. These processes are separate from the blockchain platform, but parties can only be whitelisted once they are approved. Moreover, differences in tokenization per project type even among carbon removal and sequestration types should be considered. Other, less resource intensive options should be considered as well.

The World Bank simulated a Climate Warehouse meta-registry to demonstrate the potential of a decentralized IT approach to link registry systems for the Paris Agreement [The World Bank, 2019]. A registry was created based on separate, mostly excel based registries which were integrated into the distributed ledger. A front-end interface was developed such that each user could observe the data registered. They aimed to design a simple but scalable architecture by using blockchain as the main database and keeping the traditional database, to be updated via the blockchain. The meta-registry also allowed participants to remain in control of what data they shared. The pilot shows that simpler blockchain configurations and methods exist, able to ensure that credits are not registered or sold twice without tokenization.

To become fully transparent a public blockchain is the more obvious choice, but a public blockchain limits the control one has over the operational and access rights of the blockchain. For the VCM, a sustainable blockchain has to be chosen, which is well-maintained by its network provider and has little risk of being discontinued. Besides, as there are approximately six large issuing bodies, these all have to agree to the transition towards a singular blockchain as well as give up control over their data. Moreover, if a single blockchain has not been established via the market, a consortium of actors would have to be established to design a market-wide solution similar to the results in the studies of Rukanova et al. [2021b] and van Engelenburg et al. [2020]. Such consortium's would be more likely to adopt a hybrid blockchain as it reserves more constitutional rights for the consortium and administers greater control.

6.8 META-REGISTRIES

Following the trade-off between centralization and decentralization, a solution discussed several times for double counting along with the dispersed market was a meta-registry. A meta-registry consists of bridges towards other blockchains, and databases via application programming interfaces. Multiple parties are working on such meta-registries to capture the VCM [Adams et al., 2021; IHS Markit, 2022; The World Bank, 2019]. The world bank conducted a pilot on connecting climate markets, called a climate warehouse, via blockchain [The World Bank, 2019].

Table 6.11: Quotations on meta-registries as a solution

Theme	Quote	Individual
Meta-Registry	*"As long as it is clear where all that data comes from, then it does not matter that you have to go one single place."*	Blockchain Expert 1
	"And yeah, so I think that's also a possibility that I'm really curious where the market is going, because I saw like, because because I think Markit is working to make the registry, a real bank, is working on a registry, Microsoft's is working on a meta registry. So I think in the end, there should be only one registry, right?"	Blockchain Expert 2
	"Yeah, I mean, ultimately we want our software to be for any project that can use our registry."	Blockchain Expert Toucan
	"But I think it's about a mechanism that every party agrees with. And I think blockchain is only a limited added value in that regard."	Founder Acorn

IHS markit has launched a meta-registry recently in collaboration with several banks and issuing standards [IHS Markit, 2022]. The pilot of the world bank showed that participants experienced an increase in trust and transparency. Nonetheless, additional guidance for participants was needed as most were new to using blockchain-based infrastructures. The pilot also highlighted that blockchain technology is one piece of the puzzle. Additional considerations on the governance and the possibilities for integrations with other technologies for audit purposes were required [The World Bank, 2019].

Remaining questions and lessons learned were:

- What are permission arrangements that could be introduced to differentiate between users that have only access, versus actors that are responsible and liable for changing information in the system?
- In terms of other technology their could be potential in artificial intelligence with respect to redundancy of data and data quality.
- A flexible model should be designed, such that it can adapt to governance related market developments arrangements as well as technology developments.

The pilot showed a simple version of a meta-registry, pulling the data from dispersed registries via simple excel integration. A meta-registry can also be based on a blockchain based registry that forms bridges with a multitude of existing blockchain registries. The benefit of this system is that existing ecosystems remain in place and credits do not have to be retired in one system to become live on another system (said meta-registry). However, a meta-registry via bridging is however not a holy grail. If a meta-registry is established that uses bridging to prevent double counting, a blockchain explorer could be employed to identify to whom credits are registered and what credits are sold. To identify double counting in this setting, manual cross-matching would have to be performed using the blockchain explorer which could be very labour intensive.

Predominantly, trying to create a meta-registry raises the issue of data ownership, firstly who is supposed to own the meta-registry and secondly if standards, like Verra and Gold Standard are willing to give up sole ownership of the data on their registries. As discussed, also the necessary technical difficulties come into play when creating a meta-registry. The difficulties depend on the type of meta-registry that is considered, bridging blockchains that tokenized carbon credits or integrating traditional database registries that use excel sheets for example.

Table 6.12: Governance Requirements of Meta-Registry

Governance Rights		Category	Open Issues
Constitutional Rights	Alienation	Ownership	Who should own the registry?
Collective Choice Rights	Management	Classification	What type of credits may be sold?
	Exclusion	Quality	Who is allowed to sell credits?
Operational Rights	Access rights	Integrity	Who is allowed to buy credits?

6.9 ACORN'S BLOCKCHAIN SOLUTION IN A GLOBAL SETTING

In Chapter 5, the proposed improvements for Acorn's blockchain based platform were discussed considering the direct stakeholder context. Consecutively, after integrating the social and technical domain in a global setting, the blockchain-based platform of Acorn can be discussed in the wider context. In the absence of a single actor or entity heading the market shift towards blockchain, banks are seen by leading standards as capable parties due to their regulated nature [Chow, 2022]. As mentioned, they have sophisticated processes in place which can help regulate who can buy credits and regulate to for what purpose the credits are used. Acorn can take advantage of unique position by becoming one of the first bank-related institutes to supply and trade CRUs on their blockchain-based market place.

To become a market leader, Acorn needs to be able to onboard credits from other issuing mechanisms. Only then, it can start to map part of the global market. The more Acorn could cover in this way, the bigger its infrastructure gets, and the remaining, fragmented share of the market will shrink. At this point, Acorn can address the global market to some extend and prevent double counting for all credits on the platform, which is when the added value of their marketplace becomes tangible. Despite the possibilities of the proposed blockchain-based platform and its spillovers towards the global market, the caveats in Table 8.1 still pose a challenge. As the analysis showed, the trade-off between centralization and decentralization is present in Acorn's its solution. The technical feasibility of decentralizing the information gathering processes, combined with adequate tokenization, is the main conundrum that holds the adoption of the blockchain-based platform back. Additionally, the lack of regulations in the market make it difficult for Acorn to demarcate its marketplace.

Meanwhile, many technology providers are working hard to become the first large party to facilitate robust credit tokenization. One of the conditions for the proposed platform to prosper and accrue the desired spillover effects is to be one of the first technology adopters, able to provide a robust marketplace with adequate tokenization. As the market will reach an equilibrium in time when the best performing platforms dominate the market.

Concerning the architecture, no new improvements have surfaced but some additional stakeholders are considered the final proposal, see figure 6.2. What can be observed in figure 6.2 are the monitoring actors, comprised of government agencies, supervisory bodies, and corporations, who require transparency in the provenance and transactions of carbon credits. As the blockchain is based on a public, permissionless network anyone can access and write to the blockchain. All transactions, data changes, and credit-related information are accessible to the public. The infrastructure would allow acorn to report to national authorities on a global level per country, likewise, companies, NGOs, and any other monitoring & verification bodies can access the information. Based on the findings and previously identified considerations, the following requirements are established in Table 6.13 when Acorn desires to move forward with the implementation of a blockchain-based marketplace.

Table 6.13: Requirements for Acorn's Market-Wide Blockchain Solution

Code	Requirements Acorn's Blockchain Solution
RQ1	Credits have to be durable
RQ2	Only newly minted credits should be put on-chain
RQ3	Supply has to be continuous to create liquidity in Marketplace
RQ4	Only CRUs should be sold on the blockchain
RQ5	Be the first mover on tokenizing Agroforestry Carbon Removals
RQ6	Able to join other issuing mechanisms related to KYC processes
RQ7	Ensure data integrity through data standards
RQ8	Organize reporting to facilitate monitoring for wide range of entities
RQ9	Able to on-board similar removals from other suppliers

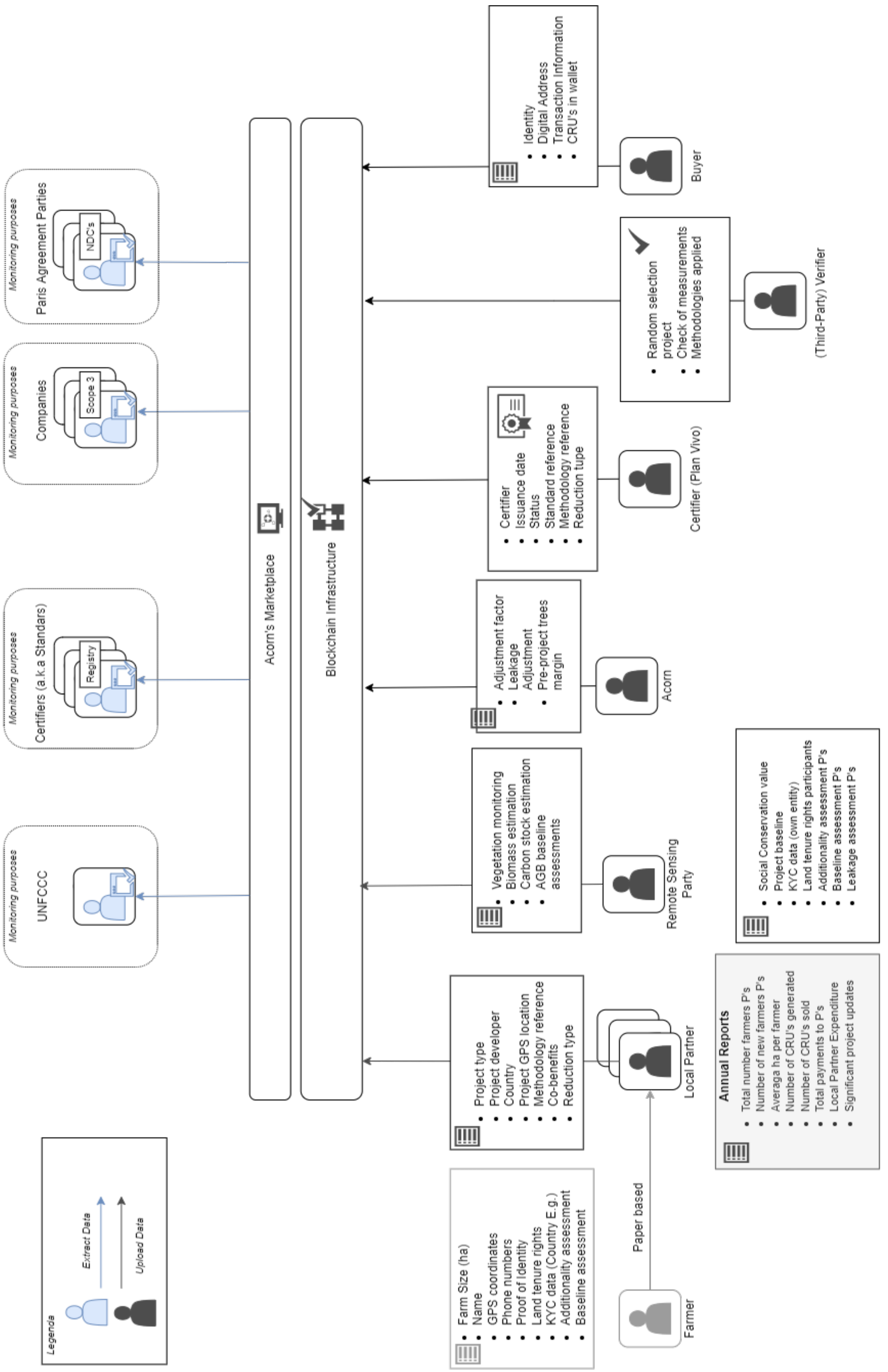

Figure 6.2: Blockchain Model Acorn Solution

6.10 CONCLUSION CHAPTER 6

Chapter 6 set out to integrate the social and technical dimension of double counting. Through this integration the technical requirements derived from the case study analysis are combined with complex the stakeholder dynamics present in the VCM, thereby answering sub-question 4: *How does the Acorn solution contribute to addressing the wider problem of double counting, adopting the wider stakeholder perspective and what are additional aspects that remain to be addressed to achieve an industry solution?*

The case study of Acorn demonstrated, on a very detailed level, that successfully implementing blockchain-based applications requires considerable technical skill and expert knowledge. The combination of minting and trading carbon credits on one platform increases technical difficulty. Several requirements materialized from the evaluation of Acorn's own solution. These requirements, apart from RQ4 & RQ5, are generalizeable to any blockchain solution developed for the VCM. Furthermore, two principal trade-offs in the development of blockchain solutions emerged from the findings.

The first trade-off that materialized is the renowned question of centralization versus decentralization in information systems. Decentralization promises a more secure aggregation and trail of data, but it brings with it considerable technical difficulties. The results showed that the VCM is gradually moving towards the adoption of meta-registries, re-instating some level of centralization. Multiple initiatives and collaboratives are trying to develop and implement blockchain-based, meta-registries.

The second trade-off is the option to employ tokenization to leverage the benefits of end-to-end traceability and automated trading of carbon credits versus the not employing tokenization to ensure audit traceability and reduce technical complexity. Incorporating tokenization allows one to capture the consumer side part of the VCM, it ensures end-to-end transparency and assures the buyer of its reliability and validity. Yet, it incurs technical challenges which are hard to overcome, especially operating as a single actor. Sustainable solutions to secure the audit trail of carbon credits, are at present more attainable and can have more impact to prevent double counting.

Overall, the Acorn solution helped to identify low-level design requirements and choices for blockchain solutions. These were evaluated in the context of the VCM in its entirety. The findings demonstrated that double counting can be better prevented if blockchain solutions are established, that cover the registry of more than one actor in the VCM. It became abundantly clear that blockchain is no panacea. Far-reaching stakeholder alignment and standardization are necessary for solutions to prevent double counting. Meta-registries can prove to be very useful in addressing the issue of double counting, where data integrity and comparability remain crucial.

7 DISCUSSION

Chapter 7 reflects on the results of the thesis and simultaneously answer sub-question 5: *What extension or adaption can be proposed to the model of Van Engelenburg based on the case analysis of Acorn?* The chapter is divided into five sections. Section 7.1 compares the empirical issues experienced in the VCM to the extant literature. It is observed that the issues which emerged in the interviews are equivalent to the issues identified in the literature. A difference found in the results is that specific accounting standards were discussed less often by most participants compared to the coverage it received in literature. In Section 7.2, the feasibility of tokenization with respect to double counting is reflected on. The results from the case study show that deploying adequate tokenization for carbon credits is empirically more difficult than posed in literature. This difficulty is a result of the ambiguous legal constructs on which carbon credits are built.

Next, the main trade-off for applying blockchain in the VCM between governance requirements related to access and transparency is rationalized in Section 7.4. The following two sections pose bigger questions concerning market dynamics and the solution of Acorn compared to a meta-registry. Lastly, the question is raised if the benefits of blockchain to be experienced by the market or if a relational database management system can provide similar benefits.

Section 7.6 discusses the limitations of the framework used for theoretical sampling throughout the thesis is evaluated and subsequently, the MLGBE framework is presented as an iteration of the van Engelenburg et al. [2020] framework. First additional theory to capture the multi-level governance context of carbon markets is discussed, from which the MLGBE framework is devised. Theory is drawn from literature in the multi-level governance field, integrated with the extant framework of van Engelenburg et al. [2020]. Theory on the constructs of quality and legitimacy in markets is also unified in the MLGBE framework, to capture the influences of consumer needs and market mechanisms on governance requirements and blockchain design choices. How to apply the framework is shortly demonstrated in Section 7.8. After the demonstration, the framework is evaluated and validated in a light manner by the strategy lead of Acorn and Dr. S.H. Van Engelenburg. The evaluation and validation identify to what extent the framework fulfills its objective as well as identify opportunities for further refinement or extension of the framework.

The chapter is concluded with a reflection on the research process, concerning the choices made by the researcher. On a positive note, the thesis presented a succinct, yet thorough overview of carbon markets and double counting. Moreover, the results from the interviews provided new and unexpected insights, resulting in the MLGBE framework. In hindsight, more time could have been spent on researching the underlying properties per project, which could have added to the analysis of the technical dimension. Additional interviews with other actors would have also enriched the findings.

7.1 ISSUES IN THE MARKET

The empirical analysis identified standardization, market clarity, the link between the VCM and compliance market, transparency, and stakeholder alignment as the overarching themes part of the main challenges and solution space. Table 8.1 consolidates the main issues from the literature. The main observation is that the empirical findings are grounded in the literature as the themes found in both are rather similar.

A difference between the empirical findings and the literature is the level of inclusion of accounting standards. Accounting standards were discussed less frequently, compared to the coverage it has received in the literature [Shrimali, 2021; Ascui and Lovell, 2011; Reuss et al., 2022; Kreibich and Hermwille, 2021; Kollmuss et al., 2008]. An explanation for this result could lie in the fact that the unit of analysis of the research focused on enhancing transparency and traceability, through the use of innovative technologies i.e.blockchain. Hence, a lot of attention was directed onto the possibilities of blockchain and the stakeholder and governance dynamics influencing the blockchain.

Comparing the accounting standards is a difficult task and requires time-consuming research into the accounting standards and principles used by different entities. As little knowledge of the details of carbon accounting standards was present by the researcher before embarking on the research, the different accounting standard became a given shortcoming of the market and a detailed comparison between different accounting standards has been overlooked. A more thorough understanding of the carbon accounting practices between the mechanisms could have enriched the recommendations for Acorn itself and with to respect the global carbon market [Ascui and Lovell, 2011; Shrimali, 2021].

7.2 FEASIBILITY OF TOKENIZING CARBON CREDITS

The problem demarcation showed that double counting in itself is essentially not the issue. It is a result of the inherent market fragmentation, the lack of transparency, and standardization allowing for double counting to occur. When comparing the aspects of double counting they seem almost directly transferable to the characteristics of blockchain technology. This implies that a blockchain-based platform can easily prevent double counting. Yet, deploying disruptive technology in a new domain is never that simple [Sipthorpe et al., 2022; Rukanova et al., 2021b].

Supply chain visibility is required to trace a carbon credit from its origin up until when it is sold. Literature has shown that blockchain can provide such visibility in supply chains [Francisco and Swanson, 2018; Azzi et al., 2019; Agrawal et al., 2021; Dobrovnik et al., 2018], as well as facilitate efficient and automated transactions. Empirically, it was found that it is very difficult to tokenize carbon credits despite the technology being theoretically fit to do so. Adequate tokenization for carbon credits is dependent on a universal off-chain definition of the asset, properties that can capture the real-world asset, and token extensibility. Each of these aspects has not yet been solved in the VCM.

Additionally, it depends on how sophisticated the tokenization should be. Solely basing oneself on the vintage year, the project specifics, and amount of carbon is not necessarily difficult. The process of tokenization starts to become complex when tokenized credits are desired to be transferable, universal and behave like is expected. Multiple parties and initiatives are working on tokenizing carbon credits and some pilots with tokenized credits have been executed [Chow, 2022; Quantoz, 2022], but no tangible breakthroughs have been made at present [Sipthorpe et al., 2022].

Besides, asset tokenization might not be necessary to prevent double counting. The case of Acorn gave an example of a project developer integrating a marketplace and registry into one blockchain-based platform. Multiple studies on blockchain models for the compliance market also incorporated asset tokenization to facilitate the trading of carbon credits [Franke et al., 2020; Galenovich et al., 2018a; Al Sadawi et al., 2021]. Nonetheless, other studies demonstrated a high level of transparency and traceability by deploying blockchain without asset tokenization [IBM, 2021; Rukanova et al., 2021b; van Engelenburg et al., 2020]. In these cases, the blockchain-based platforms allowed supply chain partners to share information on provenance and logistic events with other relevant supply chain partners or consumers. Additionally, the discussed pilot of the World Bank did not deploy tokenization functionalities for their meta-registry. Depending on the purpose of the blockchain-based platform asset tokenization can either be beneficial or become burdensome

The case studies from Rukanova et al. [2021b] and Agrawal et al. [2021] have proven that the audit trail can be secured in private blockchains, whilst providing the necessary transparency to monitoring parties. It can be argued that for the VCM the first step should be to improve the reporting, monitoring, and verification practices to reduce double counting and increase market quality. In such a solution the trading of carbon credits via blockchain is left out. Creating and implementing a registry and marketplace simultaneously might lead to failure hindering the adoption of blockchain solutions henceforth.

Given that asset tokenization is deeply transformative. From the notion of digital assets, and their legal definition, to how they are created, safe kept, and managed, realizing the adoption of digital assets depends entirely on the capacity of the economic actors to re-define common standards, and operational frameworks, and regulations. The regulatory uncertainty accompanied by tokenization pose a challenge for the market to adopt tokenization. How well the voluntary carbon market is able to establish universal definitions and legal frameworks, will determine the success of carbon credit tokenization [Sipthorpe et al., 2022; Uzsoki, 2019].

7.3 CONSUMER CONSIDERATIONS

From the empirical data, it became apparent that certain tokenization of carbon credits did not have the desired effects intended by the parties first digitizing the carbon certificates. If one compares this to other cases in which B2B blockchain solutions were designed, the technical design of the blockchain was focused on creating transparency in supply chains in a way untrusted parties, part of the supply chain, could share and access necessary data without impairing their competitiveness [Rukanova et al., 2021b]. These B2B blockchain solutions did not tokenize assets, but utilized the blockchain specifically to track events and share data. Access rights and control rights were organized in such a manner that the blockchain could only be used to serve its purpose. What is observed in the carbon market is that specific blockchain configurations that incorporated asset tokenization, allowed for parties with 'mailing' intentions - making money from trading, instead of the desire for due-diligent carbon offsetting - could enter the blockchain network and exploit it [Chow, 2022]. In such a manner that tokenization of the carbon credits was deemed unfeasible due to market forces.

Due to carbon credits already being a complex legal construct, any form of carbon credit tokenization should be unambiguous and easy to understand. Digitizing carbon credits to (public) on-chain environments can mean that they become accessible to the public. Opening up the market to inexperienced consumers increases exposure, especially if quality constructs are not incontrovertible. Whereas a solution without tokenization leaves the consumer out of the picture. Tokenization allows for the carbon credits to be traded directly in a P2P manner, allocating property rights and assets securely. Tokenization presumably increases liquidity which benefits consumers and they experience newfound guarantees of the credits that they are purchasing.

By designing a solution similar to the B2B blockchains mentioned in Rukanova et al. [2021b]; van Engelenburg et al. [2020], the increased security and liquidity beneficial to the consumer are lost. The empirical analysis confirmed that trust is one of the main pillars for the functioning of the carbon market. The level of trust in the VCM is volatile and the market needs an increase in transparency, quality, and consumer reliability. Literature has also shown that such trends occur in similar markets, consumers require more assurances that products are reliable and sustainably sourced [Joo and Han, 2021; Simon-Kucher Partners, 2021]. In light of these market dynamics, it can be argued that tokenization is necessary to increase the trust among consumers and reap the full benefits of blockchain technology.

7.4 TRADE-OFF BETWEEN GOVERNANCE REQUIREMENTS & TRANSPARENCY

One of the main discussion points regarding the results is the apparent trade-off between transparency and control of governance requirements. The case study showed that Acorn itself already established the feasibility of a public blockchain [Rabobank, 2021]. In a public, permissionless blockchain the governance and consensus of validating transactions are transparent and when all required information is put on a public ledger, carbon credits can be traced back to the farmer. Moreover, the log is accessible to the general public. These constitute the main reasons for adopting a public blockchain [Zheng et al., 2017; Xu et al., 2017].

For project developers like Acorn, it is desirable to maintain some level of control over the access rights distributed to the public. Regulating who can buy carbon credits is necessary to assure that only companies with benevolent intentions purchase carbon credits [Rabobank Acorn, 2021]. Though limited, this particular control of access rights contradicts the notion of a public blockchain in which everything is supposed to be entrusted to the public Zheng et al. [2017]. Imposing such restrictions on who can act as consumers limits the transparency to a certain extent, as only specific parties are allowed to sell and buy credits [van Engelenburg et al., 2020]. The question should be posed if such constraints remain, what is the added value of adopting a public, permissionless blockchain for the platform instead of a hybrid or private, permissioned blockchain. A better recommendation could have been given if other functionalities like recommender-systems or reputation-based trading could have been explored as well [Khaqqi et al., 2018], the thesis scope itself however did not allow for the consideration of such blockchain applications.

Hybrid and permissioned blockchains have proven to be quite successful in capturing supply chain traceability, establish validation and the sharing of data among supply chain actors [Joo and Han, 2021; Rukanova et al., 2021b; Segers et al., 2019; van Engelenburg et al., 2020]. In light of double counting, establishing a blockchain-based platform with aligned data entries can improve the monitoring, reporting, and verification processes notably. Also due to the multiple constructs for verification that exist in the current market, translating these built-in checks into smart contracts can already provide the necessary immutability and security to prevent double counting.

7.5 META-REGISTRY VS SINGULAR REGISTRIES

For double counting and accounting in general, empirically it becomes clear that the easiest way to keep track of all carbon credits is to have one single source of truth, i.e.one registry. Essentially, if one registry would host all the carbon credits no double counting could take place, all credits are traceable. Also transparency is guaranteed, which is to some extent recognized in the literature [Baumann, 2018; Schneider et al., 2014].

However, as the analysis showed such a registry requires an owner of the registry. At present, this remains an issue as it is unlikely that the position if filled in the near future. Impartial parties that qualify to fill this role are uninterested and other interested parties are not perceived as unbiased by the market.

Multiple configurations of a meta-registry are possible. A meta-registry could be composed of multiple, dispersed blockchains. Beneficial is that this approach incorporates existing blockchains. A drawback is that these blockchains are separate ecosystems with different rules if they tokenized carbon credits. To prevent double counting in such a meta-registry requires a blockchain explorer that manually compares projects. Addressing double counting using such a meta-registry is inefficient and requires considerable computational power. Carbon credits from one blockchain could also not be transferred to one of the bridged blockchains. Nonetheless, such a registry would facilitate automated transactions among each blockchain ensuring security, transparency, traceability and efficiency until a credits retirement.

Another configuration of a meta-registry could be similar to the pilot of the World Bank [Baumann, 2018]. A registry that collaborates with multiple parties, among which most of the issuing standards, via excel based (or other traditional databases) integrations. This configuration does not support asset tokenization. Choosing such a meta-registry also does not enable the liquidity desired in the carbon market to regulate price stability IHS Markit [2022]. Still, it decreases the complexity of designing the blockchain considerably. At present, multiple parties are developing meta-registries [IHS Markit, 2022; The World Bank, 2019]. Naturally, only one or a limited number of meta-registries or similar blockchain solutions will prevail.

Hence, the question is whether singular blockchain solutions would function better than meta-registries developed by large entities and if they will increase their market share in time compared to these other initiatives. The case study and research show that the development of sustainable blockchain solutions requires extensive funding Sipthorpe et al. [2022]. Different scenarios on how the market develops are possible. The question remains unanswered and requires more research on both market dynamics and tokenization of carbon credits.

7.6 multi-level governance blockchain evaluation framework

Embarking on the research, the framework of van Engelenburg et al. [2020] was used for the purpose of theoretical sampling and to facilitate the emerging of new theory throughout the case study. During the case analysis several shortcomings of the framework of van Engelenburg et al. [2020] for the specific context of carbon markets came to light. Despite the framework being developed for socio-technical systems, the framework aims to apply to a more general context in comparison to the complex context of carbon markets.

The framework provided a sufficient starting point for analysing the stakeholder context, with the categorization of significant actors and identification of possible ties between different actor categories. A first shortcoming of the framework, experienced during the case analysis, is the lack of differentiation in governing/government entities, regulatory entities, and standardization entities. Allocation of the standard registries in the carbon market under the pre-defined categories would be incorrect.

Secondly, the framework does not support the analysis of the multiplicity in the business case of the stakeholder context. The case of Acorn showed continuous shifting from Acorn's perspective, to the wider context and back again, as well as replicating the various actors in different countries. Since the framework of van Engelenburg et al. [2020] does not capture this, it only supported the analysis of Acorn directly.

In general, the model of van Engelenburg et al. [2020] is not applicable to the multi-level stakeholder context of carbon markets and does not support the constant switching from local to global levels. Moreover, the framework is designed based on the use case of private blockchains in which rights could be allocated clearly. When evaluating public blockchains, rights that are allocated to nodes cannot be changed. The constitutional rights are in the hands of the public network. In this setting, operational rights can only be allocated via smart contracts and other protocol layers,van Engelenburg et al. [2020] have not captured these features in their framework and mentioned in their recommendations that these features needed more exploration.

A key characteristic of the VCM is the increasing number of stakeholders, ranging from industrialized and developing countries to businesses and NGOs at the international, national, and local levels [Mathur et al., 2014]. Climate change is a global problem, its causes and impacts, as well as the interventions needed, span from local to international levels. As a response, multi-level governance arrangements emerged to mitigate climate change. However, interventions at the local and global scales bring different sets of costs and benefits to the table and require balance for the most effective policies. Local interventions foster diversity combined with innovation and experimentation, creating flexible policy mechanisms which can adapt to local circumstances [Sovacool and Brown, 2009]. On the other hand, global approaches allow for uniformity, and minimization of transaction costs among actors and allow for better economies of scale in data collection, research, and development [Sovacool and Brown, 2009]. Ultimately, a global approach is the only way to ensure that each party bears the burdens of addressing climate change and that free-riding and emissions leakage are minimized. Still, a combined approach of global and local governance is necessary to create effective climate policy instruments [Hoch et al., 2019; Sovacool and Brown, 2009; Mathur et al., 2014]

Throughout the thesis, it has become abundantly clear that when dealing with carbon market initiatives the local and global levels, like any intermediary levels, need to be included in the analysis or evaluation. After identifying the shortcomings of the framework of van Engelenburg et al. [2020], and observing the case study results in Atlas.ti (Annex E), it became clear that additional theory about multi-level governance was necessary to capture the complex interrelations of the carbon market.

Initially, the objective was to present an extension of the stakeholder view for the van Engelenburg et al. [2020] framework in general. However, throughout the development process, it became clear that developing the framework specifically for the carbon market might be of more value. In the extant literature, frameworks focus mostly on emission trading in the compliance markets and propose frameworks to reach blockchain configurations [Franke et al., 2020; Galenovich et al., 2018a; Hu et al., 2020; Hua et al., 2020; Khaqqi et al., 2018; Kim and Huh, 2020; Li et al., 2021; Mandaroux et al., 2021; Suankaewmanee et al., 2020]. As found in the preliminary literature, no framework focused on blockchain evaluation in the carbon market and specifically not for the VCM. From supply chain and international trade literature, frameworks focus on increasing supply chain visibility and information exchange supported by smart contracts [Agrawal et al., 2021; Francisco and Swanson, 2018; Sinha and Chowdhury, 2021]. Finally, with the interrelated components of the new framework, the framework is applicable to both carbon markets and other multi-level governance domains in which blockchain tokenize assets.

The multi-level governance framework adopted from Shigaeva et al. [2013] was part of their research on sustainable land management in Kyrgyzstan and Tajikistan. The goal of the researchers involved is to improve the quality of life for people of the mountain areas in Central Asia. According to Shigaeva et al. [2013] the communities living in Kyrgyzstan and Tajikistan face substantial challenges to sustainable livelihoods, ranging from poverty and deteriorating infrastructure to climate change and natural disasters, similar to the small-holder farmers linked to Acorn and communities involved in carbon offsetting projects.

They adopted a multi-level stakeholder approach to sustainable land management, as it among other things recognizes the interconnections of stakeholders acting at different levels of decision-making. sustainable land management practices are too part of carbon offsetting projects. Shigaeva et al. [2013]'s framework therefore poses as a suitable base to illustrate the different stakeholder levels in carbon offsetting projects, and to map the mechanisms affecting these levels as well as their interrelations. In Figure 7.1 the MLGBE framework is presented.

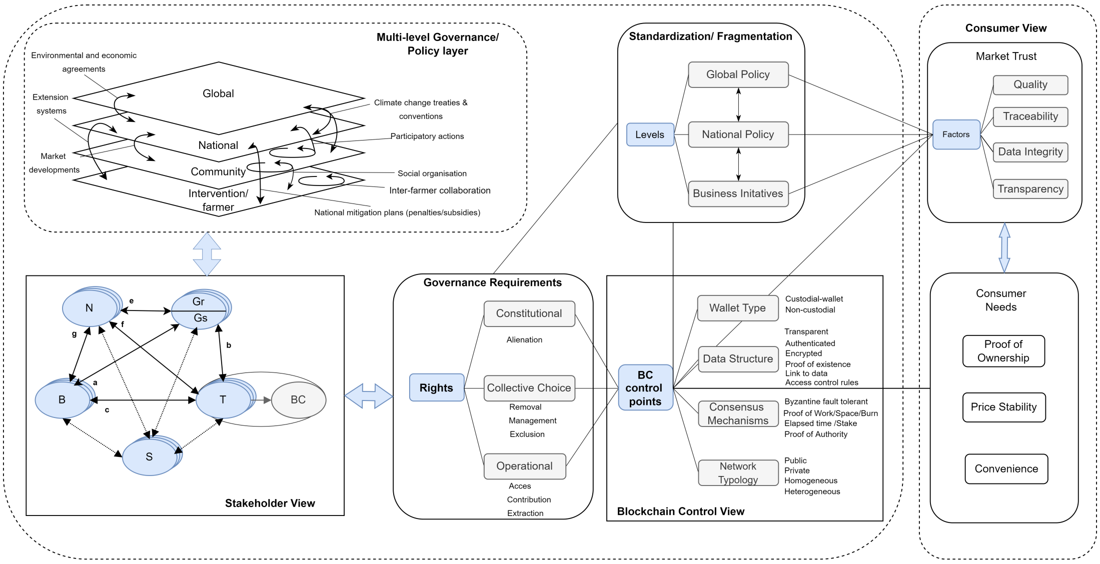

Figure 7.1: Multi-level Governance Blockchain Evaluation Framework for Carbon Market Applications adapted from van Engelenburg et al. [2020] & Shigaeva et al. [2013]

7.7 FRAMEWORK EXTENSIONS

Looking at the stakeholder view in 7.1 an extension of the stakeholder view can be observed. van Engelenburg et al. [2020] her version left out NGOs in the stakeholder view. During the stakeholder analysis, it became clear that an additional category to map the NGOs and their relations were necessary. NGOs are taking on various roles, differing from standardization entities, to market enablers and the monitors of market quality.

Considering the blue boxes depicting the actors in the stakeholder view, van Engelenburg et al. [2020] already depicted some form of multiplicity apparent in socio-technical systems. Yet it did not provide a basis to reason about the levels on which these relations existed. Hence, the multiplicity is further extended by the multi-level governance layer connected with the large, outlined arrow indicating the connection between the two. The multi-level governance box allows the reasoning about interactions between the different levels, with respect the stakeholder dynamics. Such interactions are captured by the arrows moving up and down the different governance levels, e.g.climate change treaties & conventions between global and and national levels like the **pa!**.

Moving on to the middle part of the framework, the standardization/fragmentation block is added. The thesis showed that fragmentation and standardization in the socio-technical system are dependent on stakeholder & policy alignment. The different policy levels affect the standardization and fragmentation via the same mechanism as in the stakeholder view, namely via the governance requirements. This is depicted with the line from the governance requirements box towards the stakeholder/fragmentation box. It is important to note that the multi-level governance box represents a 'zoomed-in' version of the stakeholder view. The interaction with the different standardization/fragmentation levels should be analyzed via the governance requirements as the the thesis does not provide insight into direct relations.

Lastly, in the blockchain control view the interaction between the generalizibility of the blockchain with respect to the different policy levels is indicated with the line from blockchain control points towards the standardization/fragmentation. The addition of the Consumer view is less logical compared to the stakeholder addition, as a consumer can be classified as an actor. However they would not evaluate a blockchain architecture itself, yet their desires should be considered. Since it has been discussed how the exclusion of the consumer view can lead to unwanted responses in blockchain-based environments. Therefore, the consumer view becomes an additional aspect to consider with respect to the blockchain design and is depicted in an external box linked to the rest of the framework. The consumer view is split into two concepts, *(1) market trust* and *(2) consumer needs*. The market trust is based on quality, traceability, data integrity and transparency. Quality refers to the tokenization of the underlying asset. The value of the asset has to be captured on the blockchain and this depends on both the market standards and the asset itself. Traceability means that the origin of the asset can be traced, as well as any possible trades which relate to the blockchain design. Data integrity refers to the data that accompanies the token, if the data on which the token is based is ambiguous market trust decreases. Lastly, transparency in the assets increases market trust and again transparency can be influenced by blockchain design. The relation is depicted with the line from the blockchain control points towards the factors of market trust.

Considering public blockchains, the distribution of rights and options differ compared to private or hybrid blockchains. For carbon markets, the most important requirements are transparency, traceability, and reliability. The nature of a blockchain already enforces a high level of visibility, traceability, and reliability. Important to mention is that the governance requirements continue to be relevant since operational rights can be captured in smart contracts. If a public blockchain is chosen, collective choice rights on who operates the blockchain are appropriated to the network provider (e.g.Ethereum, Polygon, Bitcoin, etc.). Fortunately, operational rights like access rights and extraction rights remain within the decision power of the platform owner, as it can implement such rights in smart contracts.

7.8 DEMONSTRATION OF THE FRAMEWORK: THE ACORN CASE

This section demonstrates the framework presented in Section 7.6. The Multi-Level Governance Blockchain Evaluation framework serves the actors aiming to apply blockchain to improve either their monitoring, reporting and verification practices and/or facilitate the trading of assets on a blockchain-based platform. It enables them to evaluate blockchain designs related to contemporary stakeholder dynamics, policies, market requirements, and customer needs. Moreover, it can help them to pinpoint important trade-offs in the design as well as derive technical and governance requirements. The blockchain ledger or platform should trace carbon credits throughout its lifecycle in a closed-loop supply chain, possibly facilitating trading and ensuring the quality, security, and reliability of carbon credits.

The framework consists of four views: (1) the stakeholder view, including the multi-level governance box, (2) the governance requirements, (3) the blockchain control view and, (4) consumer needs. The governance requirements and blockchain control view are connected to the consumer view via the standardization/fragmentation box. Similarly to the framework of van Engelenburg et al. [2020], the MLGBE framework can be used interchangeably: 1) analyze the stakeholder dynamics, including multi-level stakeholder positions, policies and regulations, to determine what governance requirements should be met and secondly identify design choices to meet requirements and consumer needs, and 2) Determine the effect of consumer needs, and fragmentation/standardization on blockchain design choices on the meeting of governance requirements, and consecutively determine the effects on stakeholder tensions.

The first view represent the multi-level stakeholder dynamics. It depicts the stakeholder groups which are of importance in socio-technical, blockchain-based information systems.

The multi-level governance box depicts the multiplicity of actors that is depicted in the stakeholder view by the multiple boxes behind stakeholder categories. All carbon offset projects operate on different levels, differing per the type of offset project. Project developers need to consider both the national governments of the countries in which projects are situated, the local communities impacted by the intervention and the partners locally implementing the projects. The multi-level governance box depicts the different levels of stakeholders and possible policies and regulations that might be present.

Project developer, issuing standards, technology providers and NGO's can use the stakeholder view of the framework to derive which actors are involved in their operational field. By first mapping the actors, the stakeholder field can then be expanded by reasoning about multi-level governance influences; existing or new regulations that influence how actors position themselves in the stakeholder field. As in the Acorn case national laws and policies of the countries in which the projects take place have to be considered in order to successfully establish projects. In this way, they can reach conclusions on which actors and regulations are important and what influences have to be examined. These conclusions on stakeholder dynamics can then be translated into governance requirements.

The governance requirements in the second view express the rights that can be allocated in blockchain based information sharing systems. Depending on the role of the actor deploying the framework (e.g.technology provider, project developer, NGO etc.) the applicable boxes can differ. Technology providers for example are less concerned with whom has specific rights. They are interested in aligning the technology with the specific market & consumer needs, and possibly account for market fragmentation. They can deploy the framework such that they devise what fragmentation exists, which stakeholders are aligned or not and evaluate if and how this impacts their solution. This is followed by the tweaking of their solution alongside the design touch points. Such systematic evaluating will enable them to design a more robust and transferable product.

Lastly, the consumer view represent the assets tokenized on a blockchain and how they correlate to the consumer. Project developers, Issuing standards, and NGOs trying to set up meta-registries can start their evaluating based on consumer needs influencing blockchain design choices, and standardization/fragmentation and reason from thereon about governance requirements. For example, if Toucan want to design market-wide solutions they should better design quality assurances to guard price stability. This translates for example into robust asset tokenization, specific wallet types and consensus mechanisms. Evaluating the factors of market trust and how they influence behaviour allows for the design of blockchain-based applications that leverage the benefits of the technology, without unexpected repercussions.

7.9 FRAMEWORK VALIDATION

The multi-level governance blockchain evaluation framework was validated in two sessions. The first session with Van Engelenburg, the developer of the original framework, the second session was held with the carbon market expert from Rabobank. The addition of levels of governance was acknowledged as useful. In the van Engelenburg et al. [2020] framework, multiplicity was already depicted in the stakeholder view by the duplication of stakeholders. Yet, the continuous moving between levels and the relation towards governance requirements was not clearly illustrated. The left-top part of the multi-level governance blockchain evaluation framework clarifies these relations and links them to the governance requirements. Some question marks were placed on the inclusion of the consumer view as one can argue that it is both a stakeholder, but it also differs in intention from the other stakeholders. Since the results of the case study showed that the consumer view is directly related to blockchain control points, the decision was made to keep it in the framework. Also since it tailors to blockchains applying tokenization.

The choice to include NGOs was endorsed by the framework developer. The case study showed clear relations between NGOs collaborating with government agencies, standardization bodies as well as businesses to improve standardization and decrease fragmentation. The addition of an extra stakeholder does however complicate the stakeholder view and one of the prepositions of the van Engelenburg et al. [2020] framework is that it combines stakeholder dynamics, governance requirements and design choices for blockchains in a comprehensive manner. The multi-level governance blockchain evaluation framework should not lose this characteristic by over complication, additional validation workshops could further test the ease of use. Lastly, the current research did not show if each layer behind the actors related to the multi-level governance/policy layer have the same effect on each of the rights in the governance requirements.

7.10 IMPLICATIONS OF FINDINGS FOR VCM

The difficulty of implementing blockchain technology combined with the lack of governance hold the voluntary carbon market in a tight grip. The research showed that blockchain solutions can have many benefits as well as drawbacks.

A novel view on blockchain technology is that, combined with asset tokenization it could force the VCM to establish universal data properties for carbon credits. Pushing the actors in the VCM to establish the long-awaited, standardized definitions and accounting methods. The case study of Acorn showed that in the design process of their blockchain-based platform, many gaps surfaced between the definitions of real-life carbon credits and their on-chain counterparts. Hitherto, the market has been able to get away with vagueness, a lack of standardization and quality issues. Despite initiatives to increase standardization issues remained. The development of the blockchain solution required Acorn to better define what value their CRUs represent. It forced them to re-evaluate the basic notion of carbon sequestration, how it is measured, compared and digitized. This process of digitization requires for buyers and sellers to become much more aware of the product that is being traded.

Despite blockchain solutions ensuring the reliability and immutability of data once registered, they cannot guarantee that the values of the data properties are reliable. In simple terms, if the data elements stored on the blockchain ledger incorrect (either due to human error or deliberately) monitoring actors cannot rely blindly on the information held by the platform.

Moreover, the 'MLGBE' framework aids project developers, NGOs, standardisation bodies, and monitoring actors to either evaluate existing blockchain solutions or identify the considerations and requirements to design sustainable blockchain solutions. Hereafter, actors in the VCM have access to tools which help them grasp the complexity of the VCM in a single figure. Overall, the framework is supposed to reduce the isolation in which interventions have been developed up until now.

It becomes interesting when feasible blockchain solutions, among which meta-registries, start conquering the market. They have the power to disrupt the current system. Dynamics among actors will shift and the blockchain solutions will have to be adaptable and scalable. Based on the ongoing initiatives to develop meta-registries or tokenize carbon credits, it seems that the story of blockchain technology for carbon markets is just beginning. Time will tell if the broad adoption of blockchain will enhance the market or be part of its demise.

7.11 IMPLICATIONS OF FINDINGS FOR ACORN

For approximately the past two years Acorn has decided to postpone the development of blockchain-based applications indefinitely. In the meantime the market and especially blockchain technology have advanced. More and more pilots of blockchain-based registries and meta-registries are done to develop feasible solutions to address the standardization and transparency issues. Over time Acorn is presented with a choice. Actors in the carbon markets seem determined to conquer the market with their blockchain solutions. The question is not if blockchain-based registries or meta-registries will be implemented in the VCM but when. Up until now the transition to blockchain-based registries has been slow, issues remain before the technology can flourish. Henceforth, there are roughly five scenarios with respect to the technology itself and VCM developments for Acorn. The scenario's for Acorn are to:

1. Adopt blockchain, succeed and become a market leader
2. Adopt blockchain, however other parties were earlier/have better solution
3. Adopt blockchain, find to many difficulties resulting in loss of resources
4. not adopt blockchain, but in a couple years be forced to adopt another entities blockchain
5. not adopt blockchain, the market also does not adopt blockchain as well and current infrastructure is sufficient.

Figure 7.2 depicts the various scenario's alongside the axis of pursuing blockchain, being successful in doing so and combining this with the market developments to illustrate what the options for Acorn mean.

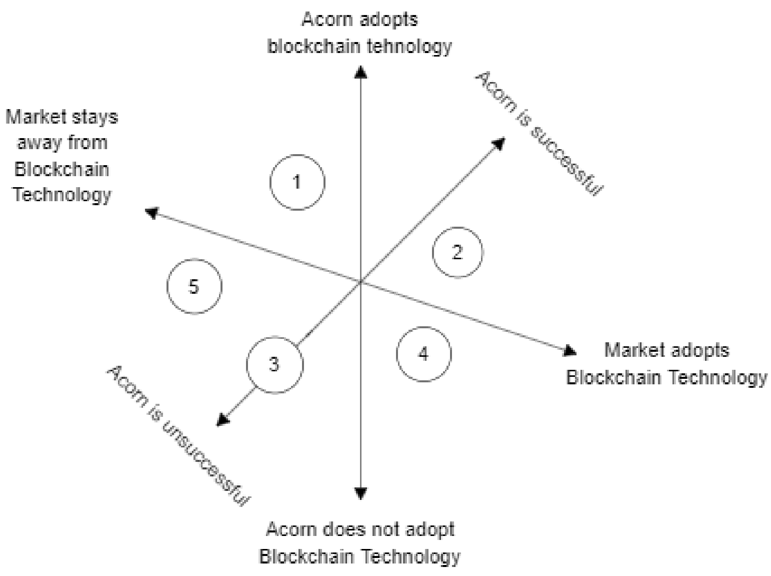

Figure 7.2: Scenario's for Acorn when adopting blockchain

Acorn should decide whether they wish to be one of the first to implement blockchain-based registries. The research highlighted that Acorn has a unique position in the VCM, as project developer, marketplace enabler complemented with the neutral image that comes along with being part of a renowned bank. The knowledge Acorn possesses on the sourcing of carbon credits, their remote sensing capabilities and participation in global governance related conferences provide Acorn with an advantage compared to other market actors. Acorn should consider joining forces with renowned technology providers, also to share the burden of financing the platform development.

As has become abundantly clear, developing a reliable and scalable blockchain solution is complex. If Acorn opts to pursue blockchain several considerations should be born in mind. Firstly, advocating for the adoption of blockchain is that a universally blockchain-based platform for Carbon Removal Units could prove to increase Acorn's in house processes as well as contribute to solving part of the inherent issues of the carbon market. By implementing the blockchain technology through-out the life cycle of a carbon credit and allowing supply-chain parties to implement their part of the data necessary to mint a carbon credit, the difficulties with standardization could be solved at last. Part of the strategy should be to determine how to (easily) onboard credits from other suppliers whilst maintaining Acorn's high quality standards. If parties of a carbon removal project's supply chain cannot provide this data it can be argued that they have not reached the desired quality and should first improve this before being allowed to sell their carbon credits.

Secondly, Acorn should start organizing their data flows, such that each actor involved in the supply chain is able to upload their own data in a compliant and reliable manner. Currently, the majority of the farmers do not have access to the hardware (and possibly the required knowledge) to access and upload the required data. Another issue to keep in mind is that a certain level of privacy for the farmer is necessary, as well as the fact that due to Acorn being part of Rabobank they are required to screen every farmer and additional parties thoroughly before they would be allowed to have upload rights on the blockchain solution.

This solution also requires adequate governance requirements of the blockchain and who has what access rights [Rukanova et al., 2021b; van Engelenburg et al., 2020]. The remote-sensing party should be able to access the data provided by the farmer and local partner, to perform its calculations and enter these next. From the other end, the buyer does not require access into the methodologies used by the satellite party since these are part of their Intellectual Property. When the carbon credit is minted on the blockchain, and all the required data fields are filled-in (GPS, provenance, certifier, carbon sequestered, Parent Project etc.) the consumer is assured of its carbon removal unit being real, verifiable and traceable [Francisco and Swanson, 2018].

This recommendation is however limited to only carbon removal units, considering the supply chain of carbon removal units also for companies with scope 3 reporting, the life cycle is the same, which means that the same data can be expected throughout the life cycles of all carbon removal projects. However, as has been thoroughly discussed, carbon removal units cannot, especially in the current state, be compared to carbon reductions. The pivotal element of this recommendation is that the value blockchain can offer is only realized when, for each supply chain party that generates carbon credits, the information flows are disentangled such that they go from being central to decentralized [Rukanova et al., 2021b].

The MLGBE framework that resulted from the case study research is based on the issues that surfaced during Acorn's own development process. The framework captures the most important trade-offs and helps to identify gaps between real-world market dynamics and digitization constraints. Acorn can exploit the framework either to support the development process of an improved blockchain solution or to demonstrate why it is unfeasible for Acorn to employ blockchain.

To conclude, how a market will develop over time is unpredictable. If other initiatives succeed to employ blockchain technology for the tokenization in an adequate manner, it might be that Acorn will have to move onto another platform, or the market might find out that blockchain technology does not bring the expected results. The likeliness of such developments have not been researched.

7.12 REFLECTION

In hindsight, there are several aspects of the research I would like to reflect on. First and foremost why I am proud of the research presented in this thesis, secondly on what I would have approached differently if I would start over. I am pleased with the synthesis of the carbon markets and the definition & depiction of double counting with respect to the VCM as. Carbon markets are particularly intricate and delineating how they functioned was crucial to make progress in the research, and significant time was allocated to this step. Should I conduct the study again, I would allocate the same amount of time to acquire this knowledge as the extensive desk research and theoretical sampling provided a sold foundation. Moreover, I am satisfied with the interview results. The line of questioning led to interesting conversations and newfound insights, which were not expected beforehand. I am positively surprised by the information richness, for example through the conceptualization of the carbon markets, process modelling of Acorn, rough architecture designs and the case study itself, reflected in the research. As the time to conduct the research was limited, some concerns throughout the research process to capture and convey all gained knowledge to were present.

Lastly, some difficulties during the research were experienced with gaining access for the case study, as well as a change in research supervision in the midst of the project. To some extend this influenced the research progress. In the end, the research presented followed the initial chosen path and improvements provided by the change in counsel could be incorporated.

As every research process also has it perils, there are several aspects that I would approach differently a second time around. One of the foremost choices would be to assert more focus on the technical design of the proposed architecture and validation of the framework. Due to time constraints, the main focus was on conducting the case study and analysing the data to develop the blockchain evaluation framework. If more focus could have been directed towards the validation of the framework, it would have increased the overall research rigor. Similarly, the conceptualization of the blockchain architecture could have been more detailed, including specific technical recommendations for Acorn for example. Also, I would have liked to include interviews from different actors in the research if the time had permitted.

8 CONCLUSION AND RECOMMENDATION

This last chapter covers the final conclusions and provides recommendations for future research. The primary objective is to address the main research question: *What framework can be developed to evaluate the benefits and limitations of blockchain-based platforms to prevent double counting in the voluntary carbon market?* Section 8.1 answers the sub questions, formulated to divide the main research question into comprehensible components. Based on the answers to the sub-subquestions the main research question is answered in Section 8.2. Section 8.3 & 8.4 present the societal and scientific contributions of the research. This is followed by an identification of the limitations stemming from the research choices in Section 8.5. Section 8.6 presents the opportunities for further research. Lastly, the relevance of the research to the Complex Systems Engineering Management study program is illustrated in Section 8.7.

8.1 ADDRESSING SUB-RESEARCH QUESTIONS

8.1.1 Sub-research question 1

"What is the problem of double counting taking on both a broader stakeholder and Acorn specific perspective?"

The desk research and empirical analysis showed that double counting cannot be solved by a single entity [Francisco and Swanson, 2018; Kollmuss et al., 2008; Kreibich and Hermwille, 2021]. Double counting is a multi-stakeholder problem, whom operate on both local and global levels increasing both the difficulty of detection and prevention of double counting [Blum, 2020; Cörvers et al., 2022; Franke et al., 2020; Lang et al., 2019; Schneider et al., 2018; Shrimali, 2021]. Three core issues of double counting are experienced in the voluntary carbon market:

1. Double claiming of carbon removals between voluntary projects and NDCs.
2. Double claiming between supply chains and voluntary projects.
3. Double claiming between NDCs and supply chains.

Conditions to solve double counting are (1) transparency in emission reporting of companies and governments as well as in carbon offsetting projects and their supply chains, (2) market-wide stakeholder alignment on both standards and corresponding definitions, (3) traceability of the carbon credits, (4) improved security and decreased room for human error, and (5) unequivocal ownership.

From the problem definition of double counting the need for an improved information sharing architecture is materialized. The information sharing architecture should adhere to the following requirements:

- A transparent information systems, from bottom up project developers to top-down issuing standards and their registries;
- Support data accuracy as well as reliability;
- Automation of monitoring, reporting & verification processes

Also, there is a corresponding need, for the capability to generate, manage, and harmonize information [Baumann, 2018], in which accounting practises should be better aligned by returning to the source of emissions: *the GPS polygon*.

8.1.2 Sub-research question 2

What are the key features, benefits and limitations of blockchain architecture with respect to the prevention of double counting?

The conditions to solve double counting established in Chapter 4 are listed above. Blockchain technology enables decentralized and transactional data sharing across a large network of untrusted parties. The benefits of blockchain technology are inherent to its characteristics, immutability, transparency, efficiency and security. Key features of blockchain technology identified to solve double counting are smart contracts and tokenization. Smart contracts facilitate the automatic execution of agreements once pre-defined rules have been met [Zheng et al., 2020; Segers et al., 2019]. Tokenization allows for the representation of a given (financial) asset as a unit on the distributed ledger, such that a user can easily prove the existence and ownership of digital asset Wang et al. [2021]. The benefits of tokenization are full-history tradability, deep liquidity and traceability.

The main risk of employing blockchain technology for double counting is poor quality data entry leading to unreliable data output and worse auditability and reliability [Kilkenny and Robinson, 2018; Rukanova et al., 2021b]. Essentially, clear cut definitions of real-world asset are required for adequate tokenization Sazandrishvili [2020]. It comes down to the notion that for any digital ecosystem to function correctly, the system and its determinants need to be universally and mutually understood in its real-world setting. If tokenization is executed poorly, the lack of comparability between carbon credits remains and double counting is not prevented. On the other side, the way to reach universal definitions that are mutually understood can be the tokenization of carbon credits as it forces market actors to define ambiguous contstructs.

The second limitation of using blockchain and in its extension NFTs, is that once a NFT has been minted it can only exist within the same ecosystem or network since the underlying blockchain platform limits the extensibility of the tokens [Valeonti et al., 2021; Wang et al., 2021]. This is of specific importance for the tokenization of carbon credits, as it directly influences the solution space when theorizing about creating connected registries, bridges between registries or e.g.a meta-registry.

Blockchain can also be deployed without the functionality of tokenization, implementing a more B2B related focus. This increases the ease of adoption and information sharing among, whilst reaching the main monitoring, reporting and verification requirements. Regardless, this configuration does not support the trade of carbon credits. As a result the value of blockchain technology to offer reliability and trust among consumers, is not fully exploited. When the choice is made for blockchain to be adopted the aforementioned limitations of the technology have to be understood at the start of the design phase, such that once the architecture has been established no unforeseen issues arise with respect to its transferability or generalizibility in the market.

8.1.3 Sub-research question 3

What are the benefits and limitations of Acorn's blockchain solution which can be identified by applying the framework of van Engelenburg?

Sub-question 3 addressed the analysis of the case study. It developed a value model, business process model (See Appendix 4.6) and visual representation of the blockchain solution with corresponding information flows (See Figure 5.1) in order to evaluate the design.

From the mapping of the blockchain solution several benefits and limitations were identified. The benefits of Acorn's blockchain solution would be the elimination of double selling and re-selling. The other main benefit is that the platform would have been built on a public blockchain, as such all the transactions would be transparent. Also security and immutability would be improved once the CRUs were put on the blockchain.

On the contrary, the main limitation of the blockchain solution was the centralization of data by Acorn before tokenizing the carbon credit. Considerations of Acorn for this choice are clear, (1) ensuring data accuracy, (2) maintaining partial control and (3) convenience. Despite integer intentions, accruing all data to one party who has the ability to change the data in an untraceable manner directly opposes the basic notion of blockchain technology. Moreover, the strategy for scaling the solution was not thoroughly established by Acorn. In the ideal setting, Acorn would be able to easily on-board other trusted developers onto their platform, for both supply and double counting purposes. Problematically, in the current market and lack of uniform definitions of carbon credits this is difficult. The open issues identified for Acorn's Improved Blockchain Solution are once again summarized, see Table 8.1. The issues were concentrated around, operational rights and constitutional rights related to platform accessibility, data governance, risk and feasibility.

Table 8.1: Remaining Issues for Acorn in Proposed Blockchain-Based Platform

Governance Requirements	Remaining Issues	Context
Constitutional Rights	Identity Management	Can it be feasible to perform the required KYC checks?
	Sufficient Supply	How and which suppliers should be joined on the paltform?
Collective Choice Rights	Risk	What happens if the blockchain fails?
Operational Rights	Accessibility	How can and should access to the platform for farmers be arranged?
	Goverance	How to ensure that there is no room for human error in the data?

8.1.4 Sub-research question 4

How does the Acorn solution contribute to addressing the wider problem of double counting, adopting the wider stakeholder perspective and what are additional aspects that remain to be addressed to achieve an industry solution?

The case of Acorn illustrated what effect the development of a blockchain-based platform can have on an actors' understanding of what is being developed. The analysis identified what requirements are unfulfilled in the current market (See Table 8.2. Additionally, it exposed the trade-off between centralization of data to address double counting and other fragmentation issues, versus the decentralization to ensure reliability. Decentralization promises a more secure aggregation and trail of data, but it brings with it considerable technical difficulties. The results showed that the VCM is gradually moving towards the adoption of meta-registries, re-instating some level of centralization. Multiple initiatives and collaboratives are trying to develop and implement blockchain-based, meta-registries.

The second trade-off is the option to employ tokenization to leverage the benefits of end-to-end traceability and automated trading of carbon credits versus the not employing tokenization to ensure audit traceability and reduce technical complexity. Incorporating tokenization allows one to capture the consumer side part of the VCM. Yet, it incurs technical challenges which are hard to overcome, especially operating as a single actor. Simpler blockchain solutions to secure the audit trail of carbon credits, are at present more attainable and can have more impact to prevent double counting.

The public, permissionless blockchain of the case study allowed for any monitoring, standardization or governmental entity as well as consumers to view the provenance and associated information for each CRU on the blockchain. By scaling the platform market reach can be expanded, overall transparency improved and market-wide spillover effects are expected. The expected spillover benefits are dependent on how well Acorn would be able to tokenize CRU, in such a manner that similar projects from other developers could be on-boarded as well. The added data integrity of Acorn's own processes is a given, when implementing the proposed blockchain solution. Ensuring the data integrity from other actors however poses a challenge for all market-wide solutions Segers et al. [2019].

Table 8.2: Requirements for Blockchain-Based Platforms

Code	Requirements for Sustainable Blockchain-Based Platforms
RQ1	Credits have to be durable
RQ2	Only newly minted credits should be put on-chain
RQ3	Supply has to be continuous to create liquidity in Marketplace
RQ4	The same type of carbon credits should be sold in a singular blockchain ecosystem
RQ5	Able to join other issuing mechanisms related to KYC processes
RQ6	Organize reporting to facilitate monitoring for wide range of entities
RQ7	Able to on-board similar removals from other suppliers
RQ8	Ensure data integrity among participants

8.1.5 Sub-research question 5

What extension or adaption can be proposed to the model of Van Engelenburg based on the case analysis of Acorn?

In the discussion the limitations of the van Engelenburg et al. [2020] framework with respect to the case study were identified. The first observation was made that the framework did not allow for the categorization of NGOs. They do not quite fit under either businesses, government agencies or standardization bodies. Hence, the first extension that could be made was the addition of NGOs in the stakeholder view. Additionally, it became clear that the stakeholder view in van Engelenburg et al. [2020] tried to capture the multiplicity in the stakeholder context with her framework, yet it did not allow for a thorough analysis of multi-level stakeholder governance. This gap was filled by exploring fitting theory on multi-level governance and by doing so the model of Shigaeva et al. [2013] was found, which clearly depicted the different governance levels in which stakeholders might operate. By integrating this model with the stakeholder context, new relations are captured by the MLGBE framework.

The case on which the analysis was based also employed blockchain for the tokenization of assets, which brings an additional dimension to be considered in the blockchain design. Normally the consumer can be classified as an actor but with respect to the blockchain design, it adds interactions between consumer needs and design choices. In socio-technical systems like the carbon market, the amount of fragmentation or standardization can also influence the market trust experienced by the consumer. As a result, design configurations related to transparency or data integrity can become much more important in designing a solid solution. These relations are captured with the addition of the consumer view on the rights side of the MLGBE framework.

Overall, the framework of van Engelenburg et al. [2020] provided a valuable basis in evaluating blockchain designs from a socio-technical systems perspective. It already allowed for the reasoning between high-level stakeholder dimensions, governance requirements and blockchain design choices. The subsequent MLGBE framework enables a more detailed stakeholder evaluation of blockchain designs through the incorporation of multi-level governance relations in complex settings.

8.2 ADDRESSING MAIN RESEARCH QUESTIONS

The thesis focused on preventing double counting in the voluntary carbon market, by exploring the benefits and limitations of blockchain technology guided by the framework of van Engelenburg et al. [2020] for the evaluation of Acorn's blockchain solution. To fulfill its research objective, it formulated the following main research question:

What framework can be developed to evaluate the benefits and limitations of blockchain-based platforms to prevent double counting in the voluntary carbon market?

The study addressed the main research question by performing an interpretative and instrumental case study. The method facilitates the detailed description of a phenomenon and the emergence of novel theories and new insights to emerge during the progression of the case study. Using the theoretical framework of van Engelenburg et al. [2020] throughout the thesis guided the research in choosing the necessary elements to explore and map, which also allowed for the extension of the van Engelenburg et al. [2020] framework fitted to the multi-level stakeholder dynamics experienced in the carbon market.

The issues in the VCM can be reduced to five main themes, which are all interrelated: (1) wrong classification (and understanding) of carbon reductions of carbon removals, (2) followed by a lack of standardization of a carbon credit, in both its global definition and the specific data the carbon credit should be comprised of, (3) lack of transparency in both the generation of the carbon credits and the reciprocal money flow, (4) lack of (acknowledged) governance body with vigor and lastly (5) differing quality of carbon credit projects. Together, these five themes play a role in the double counting of carbon credits and should align to be part of the solution. These umbrella themes prohibit adequate comparability of carbon credits (even within a single type of project) and aligned accounting of the carbon credits, NDCs and scope 3 emissions. It leaves room for human error on the supply side and trading of carbon credits. With respect to the consumer, the lack of transparency leads to lacking and fragile trust in both the market itself and its underlying offsetting projects, superficial understanding of the product bought and room for exploitation of market actors.

From evaluating the linkages between the stakeholder dynamics, governance requirements and the blockchain solution proposed by Acorn, the recommendations were formed. By using these three frames of observation throughout the thesis, the aforementioned issues and their interrelations could be explored and mapped for Acorn specifically. The interplay between explicating the global dynamics in the carbon markets, what that meant for Acorns' governance structure whilst considering the possibilities of blockchain technology, led to the development of the Multi-Level Governance Blockchain Evaluation framework. During the case analysis it became clear that the stakeholder view of van Engelenburg et al. [2020]'s framework did not lent itself to systematically examine the stakeholder view or evaluate the relationships of such a multi-level stakeholder field in detail. Hence, the multi-level governance blockchain evaluation framework was proposed to tailor better to the complex nature of the carbon market and other socio-technical systems alike.

This new framework allows carbon market actors to evaluate and, if applicable, reason about the various available blockchain based infrastructures to select the most appropriate one for tokenizing carbon credits and the digitized trading of these credits. By doing so, they can identify the stakeholder dynamics with all policies, interrelated treaties and community plans in place, develop and evaluate robust blockchain-based platforms and potentially reduce double counting instances. Moreover, it helps the actors in the voluntary carbon market between the trade-offs. The MLGBE framework is developed in such a manner that the concepts are generally applicable for multi-level governance blockchain-based platforms with tokenized assets.

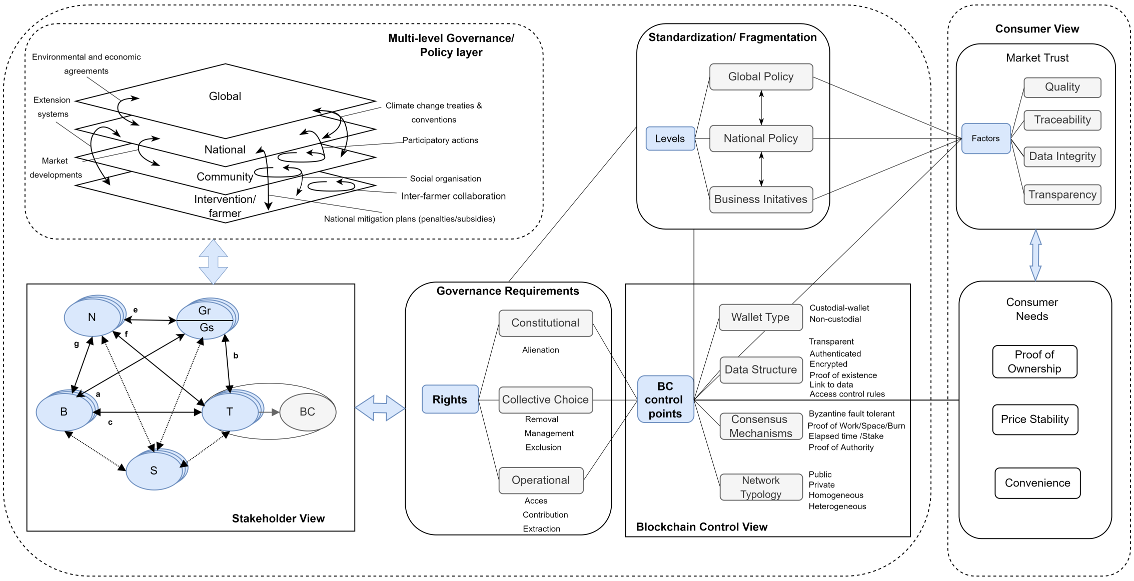

Figure 8.1: Multi-level Governance Blockchain Evaluation Framework for Carbon Market Applications adapted from van Engelenburg et al. [2020] & Shigaeva et al. [2013]

8.3 SCIENTIFIC CONTRIBUTIONS

The scientific contribution of this study is trifold: First, the research delineates the issue of double counting in the voluntary carbon market, synthesising the interrelations between the voluntary carbon market and the compliance market as well as drawing attention to empirical carbon offsetting issues. This fills the identified research gap: A comprehensive overview of the carbon market mechanisms, discerning between compliance and voluntary carbon markets, influencing and related to double counting is lacking, as well as theory that captures these interrelationships. Filling this gap, builds upon the work of Schneider et al. [2014]; López-Vallejo [2022]; Blum [2020] to define double counting and extend it towards the voluntary carbon market.

Second, potential blockchain benefits and applications for the voluntary carbon market are discussed based on the framework of van Engelenburg et al. [2020], thereby not only providing a theoretical foundation for blockchain technology, but also evaluating and highlighting real-world deployment opportunities as well as limitations. New insights on what considerations and requirements are attached to blockchain applications to tokenize carbon credits in the voluntary carbon market are found, extending on literature that discussed blockchain applications and designs in the compliance market [Franke et al., 2020; Hu et al., 2020; Li et al., 2021; López-Vallejo, 2022]. These insights also strengthen the findings of Segers et al. [2019], by corroborating the findings of the importance of reliability of data elements of blockchain-based applications used for audit-trails. Additionally, the research strengthens the acknowledgement of the relation between the generation of carbon credits and supply chains in literature, building on the work of Ashley and Johnson [2018]; Khaqqi et al. [2018]; Wang et al. [2020]

Thirdly, new theory on multi-level governance information sharing by making use of blockchain applications is build trough the development of the MLGBE framework. The framework draws on two schools of theory, namely multi-level governance and business & governance information sharing based on innovative technologies, captured in established frameworks [Shigaeva et al., 2013; van Engelenburg et al., 2020]. By integrating these two schools and adapting the frameworks the framework of van Engelenburg et al. [2020] to the particularities of asset tokenization in blockchain applications identified during the case study, a new approach to evaluate blockchain designs is presented.

The framework enriches the limited base of blockchain evaluation frameworks in literature [Pizzi et al., 2022; Sinha and Chowdhury, 2021; van Engelenburg et al., 2020; Sonmez et al., 2021].

8.4 PRACTICAL CONTRIBUTIONS

The practical contribution of this study is that through the evaluation of a blockchain application in the voluntary carbon market, the research presents a new approach to reason about blockchain designs, thereby helping project developers as well as issuing standards to determine what requirements should be met to be able to design suitable blockchain systems. Employing the framework facilitates the systematic assessment of what market needs, rules and regulations to consider in order to successfully deploy blockchain-based technology. Additionally, the framework and research insights can be employed to justify the adoption or rejection of blockchain applications by market actors as it illustrates the complexity of deploying blockchain-based technology.

The thesis, by identifying the opportunities and limitations of (public) blockchain-based systems for the tracking, tracing and trading of carbon credits in the VCM, aims at enabling market actors to access reliable information. The traceability allows actors to monitor and manage the entire supply chain system and carbon credit system processes [Wang et al., 2020]. As a result, the efficiency, credibility and consistency of carbon emission practices can be improved beginning at the supply chain level [Ashley and Johnson, 2018; Segers et al., 2019; Wang et al., 2020].

The latest IPCC report showed that the world is off-track in limiting temperature rises below 2.5 degrees Masson-Delmotte et al. [2018]. Under the mitigation scenario for 2035 global upstream scope 3 emission intensities need to be reduced by an additional 54% compared to a baseline scenario with reference technology [Li et al., 2019]. Corporate climate action is increasingly important in driving the transition towards a low-carbon economy Krabbe et al. [2015]. Hence, upcoming laws like the Corporate Sustainability Reporting Directive require companies to report on their scope 3 starting in 2024, to make insightful how much and where is emitted European Parliament [2021]. In response, companies have to step up their mitigation activities to either reduce or compensate their emissions. An increase of demand in the VCM by a factor of 15 or more by 2030 and by a factor of up to 100 by 2050 is expected Adams et al. [2021].

The MLGBE framework can contribute to the sustainable growth of the voluntary carbon market. It explicates what stakeholder dynamics are present in the market and how blockchain-based information systems can be organized to accelerate (or inhibit) market growth. More specifically, it supports that such systems need to cover quality, traceability, data integrity and transparency in the sourcing of carbon credits, whilst realizing price stability and proof of ownership in the market. Moreover, it clarifies the previously unconnected relations between policy interventions, governance requirements and market mechanisms in the VCM related to blockchain-based applications. This contribution can be exploited by NGO's, businesses, standardisation bodies etc. to develop or improve information systems to improve the legitimacy of the VCM.

8.5 RESEARCH LIMITATIONS

A first scoping choice was to focus only on carbon-dioxide when considering greenhouse gases. The other gases like methane, nitrous oxide, hydrochlorofluorocarbons, hydrofluorocarbons and ozone were left out of scope. This reduces the number of carbon offsetting projects that fall under the study scope. Moreover, the thesis decided to focus only on carbon removal projects, exclude carbon reductions, and within removal projects focus on agroforestation.

The choice to disregard varieties among different types offsetting projects and excluding capture & destruction of High-potency GHG, constitute a research limitation. The proposed recommendations do not capture represent VCM to its full extent. The evaluations, conclusions and recommendation are not directly transferable to other types of projects and might not be easily generalized for these type of projects. Actor dependencies as well as information streams might differ in carbon reduction projects, rendering different requirements for the blockchain-based platform.

To the thesis' knowledge, this is only the second time a blockchain-evaluation framework is presented that connects high-level stakeholder dynamics to low-level design choices in blockchain-based applications. Therefore, as with any novel theory, it is likely that the framework can be refined in future iterations. The limitations of the framework used for theoretical sampling throughout the thesis have already been highlighted in the discussion and are therefore left out of the limitations. Due to the infancy of blockchain technology employed in the VCM, gray literature was required to supplement academic and industry publications, leading to uncertainty over the validity of sources. When gray literature was required, care was taken to choose reputable and established sources, such as national and international media rather than advocacy websites.

The case selection of Acorn to analyze their stakeholder context with respect to their blockchain-based platform solution might have influenced the generalizibility of the research its output. The choice to focus specifically on agroforestry offsetting projects was mainly based on the access to actors in the carbon market. Since the expertise of Acorn was on Agroforesty the focus of scope logically followed. Moreover, Acorn is part of a bank and the traditional image that are part of a bank spillover to Acorn, and its market position as well. If the case study would have been through the lens of one of the leading standards, the findings related to blockchain technology and its feasibility might be presented in a different light.

Furthermore, acquiring valuable access to perform the case study was difficult. As the market is specialized, information rich and fast-moving, actors can be reluctant to share specific information on their operations. Once the relationship was established, Acorn was incredibly helpful in sharing information and allowing the researcher thorough access. Acquiring access in itself was more difficult than previously expected, part of the reason why a single case study approach was followed. Interviews with experts in carbon markets and blockchain and Acorn employees could lead to an inherent bias. Efforts to reduce this were taken by interviewing experts from different areas of Acorn as well as from several technology providers and by presenting results externally for feedback to the research committee. To further deepen the richness of information, beliefs from large standardization or government agencies should be incorporated. At present, the thesis covered only two of the five actor categories identified in the study.

Additionally, to strengthen the research results, it would have been interesting to do a cross-case analysis by incorporating multiple project developers in the case study. This would also have facilitated more insights into streamlining carbon credit differences among project developers.

A last limitation of the research is that the changes after cop-26 could only be briefly touched upon and that concepts like corresponding adjustments and its influences on the VCM had to be generally left out of scope. Similarly, the time allotted for the research did not allow for an in-depth evaluation of the carbon accounting practices, specifically scope 3 reporting with respect to the supply chains, in which another dimension of the complex mechanisms of the carbon markets can be found. Diving deeper into the delineation of scope three supply chain reporting, compared to NDCs and carbon accounting in general could have provided more insights on how to better align the accounting practices.

8.6 RECOMMENDATIONS FOR FUTURE RESEARCH

This research aims to set the groundwork for future studies, including a more comprehensive review of blockchain-based applications to address double counting.

Firstly, the primary focus of Acorn has been on carbon removal, this scope was adopted for the thesis to keep the research comprehensible for the allotted time and resources. However, carbon removals are half of the whole story. All other projects are based on carbon reduction. To bring carbon reductions into the story, additional research is necessary to identify the requirements for carbon reduction units is recommended. This asks for the mapping of a carbon reduction life-cycle of such credits with respect to the required data and information flows similar to what has been analyzed in this research. A universal definition of carbon credits is still lacking. Multiple entities are making steps to improve standardization and to delineate universal properties for tokenization. Despite such efforts some ambiguity remains, future studies could built on this research to establish adequate and universal properties.

Considering the MLGBE framework, the interaction between the standardization/fragmentation dependent on policy layers and the different rights in the governance requirements needs more research. The thesis could establish the relation between these two frames, however it remains unclear how the rights are affected and to what extend. Also, if this differs regarding the different policy layers.

To prevent double counting henceforth and streamline the market, future research should compare extant carbon accounting practices. Identifying which similarities and discrepancies exist for example between NDCs and the VCM, to lowest level of units of measurement like the length, width, and heights ratio's used in agroforestation. A better delineation of scope 3 accounting and reporting, could provide companies with better, more transparent accounting methods. Concerning double counting, further research is required on the potential of blockchain solutions to link schemes together to facilitate a global carbon market, how these could be linked to the eventual implementation of Article 6, and the potential nesting within countries' NDCs. Additionally, more research should be conducted on the feasibility of meta-registries and the transferability of credits between singular blockchain ecosystems.

Lastly, what is observed in the carbon market is that specific blockchain configurations, allowed for parties with the 'wrong' intentions - making money from trading, instead of the desire for due-diligent carbon offsetting - could enter the blockchain network and exploit it. In such a manner that tokenizing the carbon credits was deemed unfeasible due to market forces. It is recommended that further research looks into the consumer side of the carbon market with respect to asset-backed tokenization for blockchains and explore how the technical design choices allowed for such unexpected market forces to occur and operationalize the (bi-directional) influence they appear to have.

8.7 RELEVANCE TO COSEM PROGRAM

This thesis research is part of the program from the masters Complex Systems Engineering and Management (CoSEM). During CoSEM complex socio-technical systems are designed in an institutional setting. Approximately, a year ago the VCM received lots of critique due to contested quality of carbon credits circulating in the market. The VCM is a complex socio-technical system by nature because of its multitude of entangled stakeholders and fragmented information systems. Opaqueness, volatility and stakeholder differences plagued the VCM and prices dropped. Meanwhile, distributed ledger technologies kept on developing and reached a new maturity level as the need for universal market standards, stakeholder alignment and quality improvements remained.

A new challenge to create transparency, traceability and streamline accounting practices in the market via a new information sharing architecture emerged. Blockchain appears to be the chosen innovative technology by VCM market actors to facilitate such information sharing.

This research responded to the challenge by performing an exploratory, instrumental case study to analyze the possibilities of blockchain technology. The thesis presents a multi-level governance blockchain evaluation framework by integrating multi-level governance and stakeholder dynamics with technical design options of an innovative technology, to prevent double counting to enhance the legitimacy of the VCM. Overall, seamlessly following the CoSEM curriculum

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A INTERVIEW PROTOCOLS

To elicit the necessary information from the interviews, interview specific protocols were designed for different groups of actors.

A.1 ACORN – STRATEGY LEAD

The interview protocol for the strategy lead was slightly different than for the Acorn blockchain experts. One of the reasons was that this interview was the one of many conversations had with the strategy lead and basic questions had been answered. Still the first part of the interview focused on the stakeholder dimension, and since the strategy lead is involved in different conferences on the proceedings of the VCM some additional questions were asked.

Interview protocol for Acorn case study participant Project: TU Master Thesis - Complex Systems Engineering & Management: "Untangling the Wild West, A research into the issues experienced in the VCM and the possibility of digital information infrastructure to prevent double counting

1. ***Stakeholder, dynamics & Power***
   - How do you perceive the global market is addressing double counting, which parties are main drivers here?
   - What parties in the global market are most important in improving standardization? How do they relate to Acorn?
2. ***Buyer Convenience***
   - What is for Acorn's buyer important with respect to the selling process of the credit?
   - What makes a buyer want to buy from acorn instead of other registry parties?
   - What other options does a buyer have to buy credits from?
   - How does Acorn try to make sure that their credits are not sold anywhere else?
3. ***Governance of the blockchain***
   - If parties would be able to upload their data to the blockchain themselves, what data would still reside within Acorn and be uploaded by Acorn?
   - What do you think is the way to move forward for Acorn with respect to blockchain?
4. ***Global questions on solutions for double counting***
   - What do you think needs to happen in order to solve double counting?
   - What do you think could be best practice for data reporting/the information flow to improve comparability?
   - What changes do you think the market has to undergo to support such solutions?

- How do you think the market will evolve with respect to blockchain applications in the carbon market?
- How do you perceive interoperability between your blockchain application and others who also provide carbon credits?

A.2 ACORN – FOUNDER

Interview protocol for Acorn case study participant
Project: TU Master Thesis - Complex Systems Engineering & Management: ”Untangling the Wild West, A research into the issues experienced in the VCM and the possibility of digital information infrastructure to prevent double counting

Can you tell me a about your role within Acorn?

- How did you come up with the idea of Acorn/how was it founded?
- Why did you decide to enter the carbon market specifically?

1. ***Stakeholder, dynamics & Power***

- What parties in the global market are most important in improving standardization?
- Which parties are involved with respect to the blockchain solution?

2. ***Buyer Convenience***

- What is for Acorn's buyer important with respect to the selling process of the credit?
- What makes a buyer want to buy from acorn instead of other registry parties?
- What other options does a buyer have to buy credits from?
- How does Acorn try to make sure that their credits are not sold anywhere else?

3. ***Decisions on halting blockchain***

- What was the reasoning behind not pursuing blockchain for Acorn?
- What do you think is the way to move forward for Acorn with respect to blockchain?

4. ***Global questions on solutions for double counting***

- What do you think needs to happen in order to solve double counting?
- What do you think could be best practice for data reporting/the information flow to improve comparability?
- What changes do you think the market has to undergo to support such solutions?
- How do you think the market will evolve with respect to blockchain applications in the carbon market?
- How do you perceive interoperability between your blockchain application and others who also provide carbon credits?

A.3 TECHNOLOGY PROVIDER – TOUCAN

Interview protocol for Acorn case study participant
Project: TU Master Thesis - Complex Systems Engineering & Management: "Untangling the Wild West, A research into the issues experienced in the VCM and the possibility of digital information infrastructure to prevent double counting

1. ***General Questions***

- What is the aim of Toucan?
- Can you explain to me what Web 3 is and why Toucan is pursuing this?
- For which applications is the blockchain platform designed?

2. ***Carbon Market***

- Why did you decide to enter the carbon market specifically for your blockchain?
- Were there any concerns or difficulties with entering the market?
- How do you perceive data standardization with respect to tokenizing carbon credits for the blockchain?
- Were there any thoughts on quality issues within the carbon market?

3. ***Blockchain Technology***

- What specific tokenization did Toucan use and why?
- What were the requirements for the blockchain to adhere too? consensus mechanism was chosen and why? were the considerations with respect to data storage on the blockchain?

4. ***Demand and Price Signals***

- How would Toucan drive carbon credit demand and higher price signals to catalyze new environmental project development?
- There is a lot of focus on price differentiation due to the differing of carbon credits, how do you see this effecting the carbon credit market?

5. ***Global questions on solutions for double counting***

- What do you think needs to happen in order to solve double counting?
- What do you think could be best practice for data reporting/the information flow to improve comparability?
- What changes do you think the market has to undergo to support such solutions?
- How do you think the market will evolve with respect to blockchain applications in the carbon market?
- How do you perceive interoperability between your blockchain application and others who also provide carbon credits?

A.4 TECHNOLOGY PROVIDER – QUANTOZ

Interview protocol for Acorn case study participant
Project: TU Master Thesis - Complex Systems Engineering & Management: "Untangling the Wild West, A research into the issues experienced in the VCM and the possibility of digital information infrastructure to prevent double counting

1. ***General Questions***

- What is the aim of Quantoz?
- For which applications is the blockchain platform designed?

2. ***Stakeholders***

- Why did you decide to enter the carbon market specifically for your blockchain?
- Were there any concerns or difficulties with entering the market?
- How do you perceive data standardization with respect to tokenizing carbon credits for the blockchain?
- Were there any thoughts on quality issues within the carbon market?

3. ***Blockchain Technology***

- What specific tokenization did Quantoz use and why?
- What were the requirements for the blockchain to adhere too? consensus mechanism was chosen and why? were the considerations with respect to data storage on the blockchain?

4. ***Scaling up***

- From your perspective what data should be included to gain the most value from the blockchain?
- From your perspective, how would you optimally see the data reported to be of use for the blockchain?
- How have you considered interoperability of the blockchain?

5. ***Global questions on solutions for double counting***

- What do you think needs to happen in order to solve double counting?
- What do you think could be best practice for data reporting/the information flow to improve comparability?
- What changes do you think the market has to undergo to support such solutions?
- How do you think the market will evolve with respect to blockchain applications in the carbon market?
- How do you perceive interoperability between your blockchain application and others who also provide carbon credits?

B DATA COLLECTION PROCESS

B.1 CASE STUDY PROTOCOL

A case study protocol was developed based on Yin [2018] to guide the case study.

The Unit of Analysis

The unit of analysis is the main entity or phenomenon being studied in the case study. In this research the unit of analysis is Acorn's blockchain solution, of which it is important to note that it has not been implemented. It became clear from the desk research and preliminary discussions that Acorn viewed the market as too immature, but does see a potential in applying blockchain technology in the future. One of the aspects prohibiting Acorn from wanting to implement the solution was the issue of double counting in the market.

A question that remains is how the implementation of blockchain technology could aid in preventing double counting. Hence, the interest of this case study is the blockchain design and the lessons which can be learned from it through the lens of double counting, whilst also keeping in mind the wider perspective of the global carbon market. The elements of the design itself, as well as rationales and viewpoints of the developers will be analyzed in the context of the case study in order to identify the benefits and limitations of the blockchain solution and how Acorn's solution could set a market precedent or not.

The data gathered from the differing data sources aided in answering the case study questions designed in the case study protocol. It allows for a deeper understanding into the design choices made for the blockchain solution, stakeholder needs and dynamics and corresponding governance requirements. This insight contributes to the later analyses related to double counting and to what extend the current blockchain solution is fitted to this issue.

It is important to determine under what circumstances the results of the case study are analysed. As case study findings can have rival explanations, identifying and refuting these explanations can increase the research rigor and validity of the case study findings Yin [2018]. The case study propositions serve as a guide for interpreting the findings of the case study analysis.

B.1.1 Case Study Propositions

van Engelenburg et al. [2020] argues that by making design choices for a blockchain-based system, different ways of governing the data and the system are enabled. Hence, changes in configurations of design choices for these blockchain control points can also lead to a change in the power dependencies among the stakeholders involved. The issue of double counting is largely based on the differences between methodologies linked to actors and insufficient accounting. How the design of the blockchain impacts the stakeholder dynamics is therefore important to analyze.

On the other side the data disparities inherent to the market structure and again the actors, can negatively influence the value gained from blockchain. Hence when designing the blockchain, key decisions have to be made about what data to store on the blockchain van Engelenburg et al. [2020]. Lastly, when looking at the environment in which the blockchain-based system would be embedded in, it is thought that these improvements will have positive spillover effects for the rest of the market. Based on this knowledge the propositions are as follows:

- Use of blockchain technology will make the identification of double counting easier

- For the correct application of blockchain technology some key data decisions have to be made
- Increasing in-house transparency will lead to increased quality in the global market

Case Study Questions

Asking the right questions is essential to the success of a case study Mills et al. [2009]. The questions guide the answers towards the direction set out for the case study. The case study is conducted to examine the social domain of Acorn itself and its context, the influences of these stakeholder dynamics on the governance requirements and how these relate to the blockchain solution of Acorn. In support of these research goals, the following umbrella case study-questions were drafted to guide the data collection:

1. What actors are main determinants in the case with respect to double counting and what are their different levels and resources?
2. What inter-dependencies exist between these actors?
3. What issues did Acorn want to try to solve with the application of blockchain technology?
4. Which reservations exist with respect to applying blockchain technology in the case?
5. What are the main drivers of blockchain technology influencing Acorns current governance processes?
6. To what extent is the current blockchain solution suited to address double counting?
7. What improvements to the blockchain architecture can be identified to best tackle double, counting, considering the information needs?

B.2 INFORMATION SOURCES

Table B.1: Information Sources

Sources of Information	Number of sources consulted
Rabobank Acorn (Internal) Documents	Five Documents consulted
Research articles	One white-paper
Documents	Five rapports
Interviews	Seven interviews
Webinars	Four webinars

The main document used was the Latest Digital Marketplace Acorn (V0.8), an in-house white paper presenting a blockchain solution for Acorn's Marketplace including the considerations and research backing the solution. Apart from this document, Acorn shared multiple in-house documents, of which one document was a memo. The other documents contained a typology of the market, blockchain research, email correspondence on the definition of double counting. Two other documents were recently made publicly available, called the Acorn Framework and the Acorn methodology disclosing information on how Acorn organized their platform, their guiding principles and in-depth information on how they measure carbon sequestration.

Three webinars were attended online. The first webinar was a webinar from Acorn, presenting their framework and methodology and diving deeper into the aim and successes of Acorn. The next webinar attended was on tokenizing carbon savings by Quantoz Blockchain Technology. They presented their Nexus technology to create a regulatory compliant carbon credits market on the Algorand Blockchain. The last webinar was provided by compensate, elaborating on scope three emissions reporting for companies.

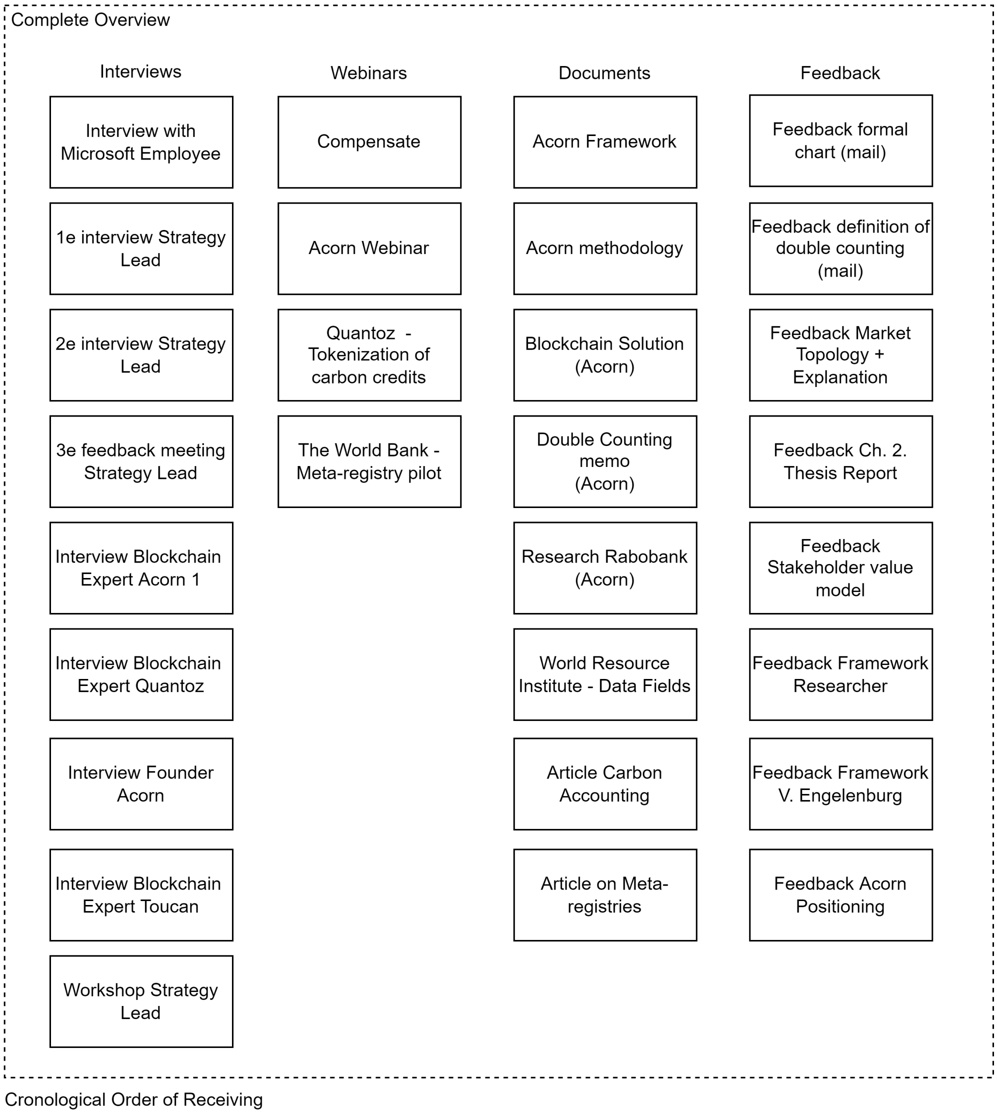

Figure B.1: Overview empirical data gathered for Case Study

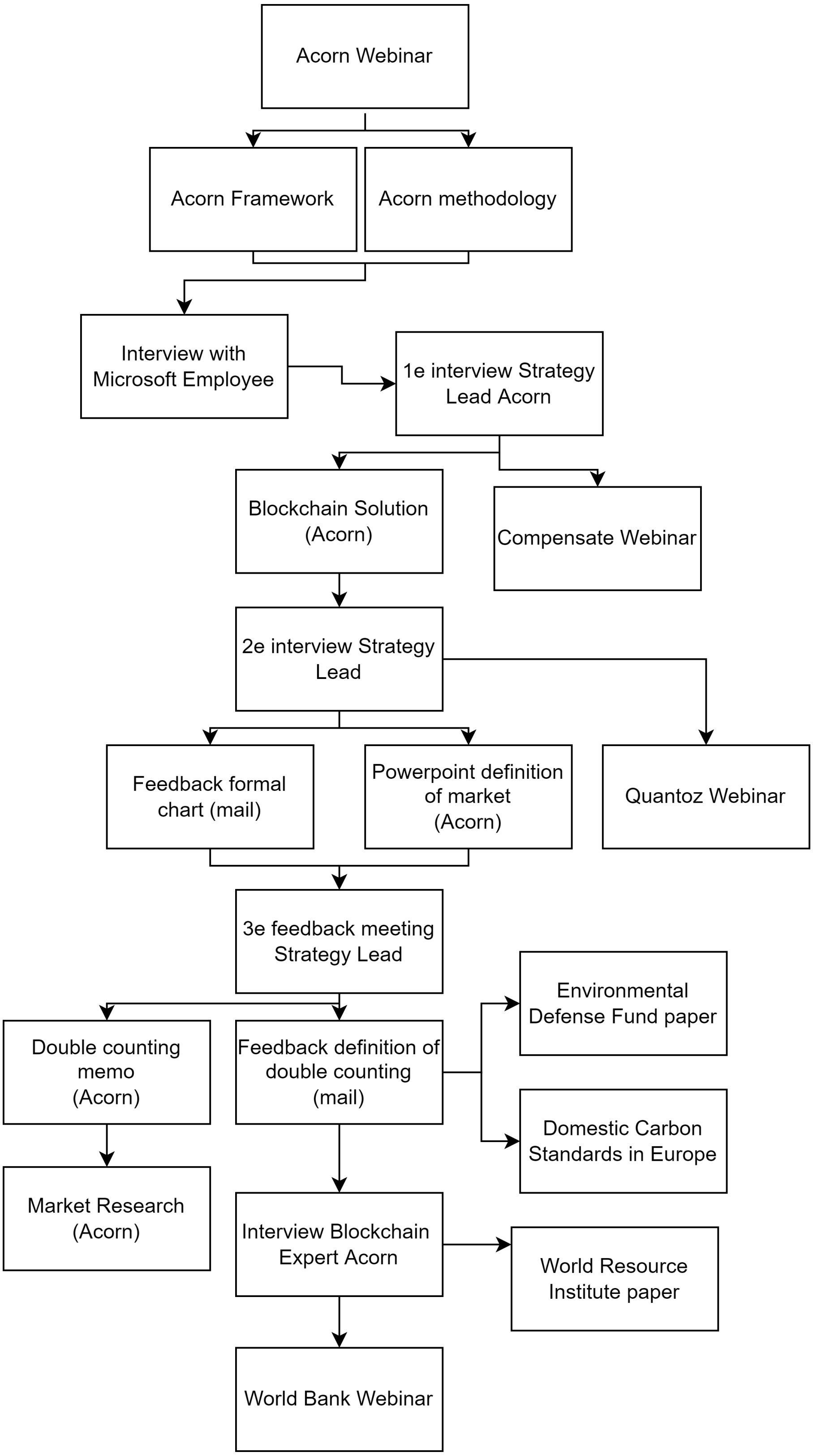

Figure B.2: Data Library

The workshop was held at the Rabobank headquarters. A whiteboard was used to brainstorm about the findings from the interviews, related to the case of Acorn and placing these findings in the context of the VCM. Figure B.3 displays the outcome of the workshop. On the left hand in the figure the issues present in the VCM were summarized. On the right side the challenges of blockchain technology were delineated and in the middle the lifecycle of a token based on Acorn was drawn. During the brainstorm the different parts of the problem were connected to eachother through the arrows.

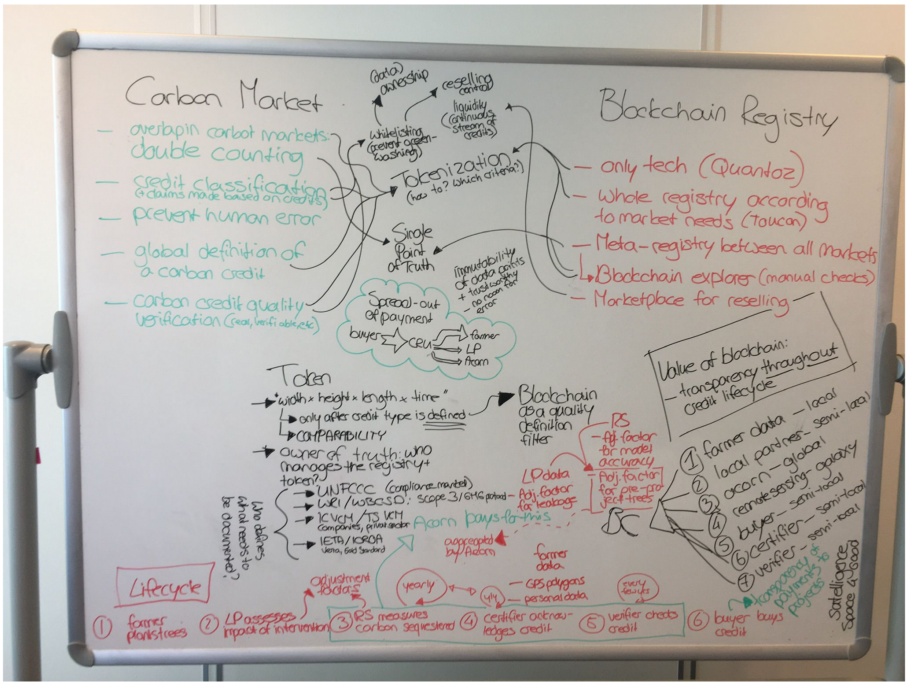

Figure B.3: Result of Workshop

B.3 CODING STRATEGY

A strategy, can be used in the form of a carefully considered plan or method to achieve a particular goal, which is in the case of this research theory building from rich empirical data on Acorn. Leavy [2014] describes coding as *"a heuristic—a method of discovery—to the meanings of individual sections of data."* (p. 581). Such codes function as a way of patterning, classifying, and later reorganizing the data into emergent categories which can be used for further analysis.
The data suitable for coding ranges from interview transcripts, to journals, to photographs, to documents and many more data sources. The portion of data to be coded can vary in range: it can be as short as one word, a sentence or even be an entire page of text. Such codes are supposed to represent and capture primary content and essence [Leavy, 2014, p. 586]. The categorization process consists of the reorganizing and reordering of the vast array of data because according to Leavy [2014] *"it is from these smaller, larger, and meaning-rich units that we can better grasp the particular features of each one and the categories' possible interrelationships with one another."*

To analyze the data gathered from the case study the computer-assisted qualitative data analysis software Atlas.ti will be used. The tools of the program provide guidance and help to code and categorize large amounts of data. In order to make good use of the program, an initial frame of general concepts and themes was established to guide the coding process [Leavy, 2014]. Crowe et al. [2011] promotes "The Framework approach": a practical approach, comprising of five stages (*familiarization; identifying a thematic framework; indexing; charting; mapping and interpretation*), to manage and analyse large datasets, particularly if time is limited.

C INFORMATION NEEDS

Figure C.1 shows the expanded business process model of Acorn.

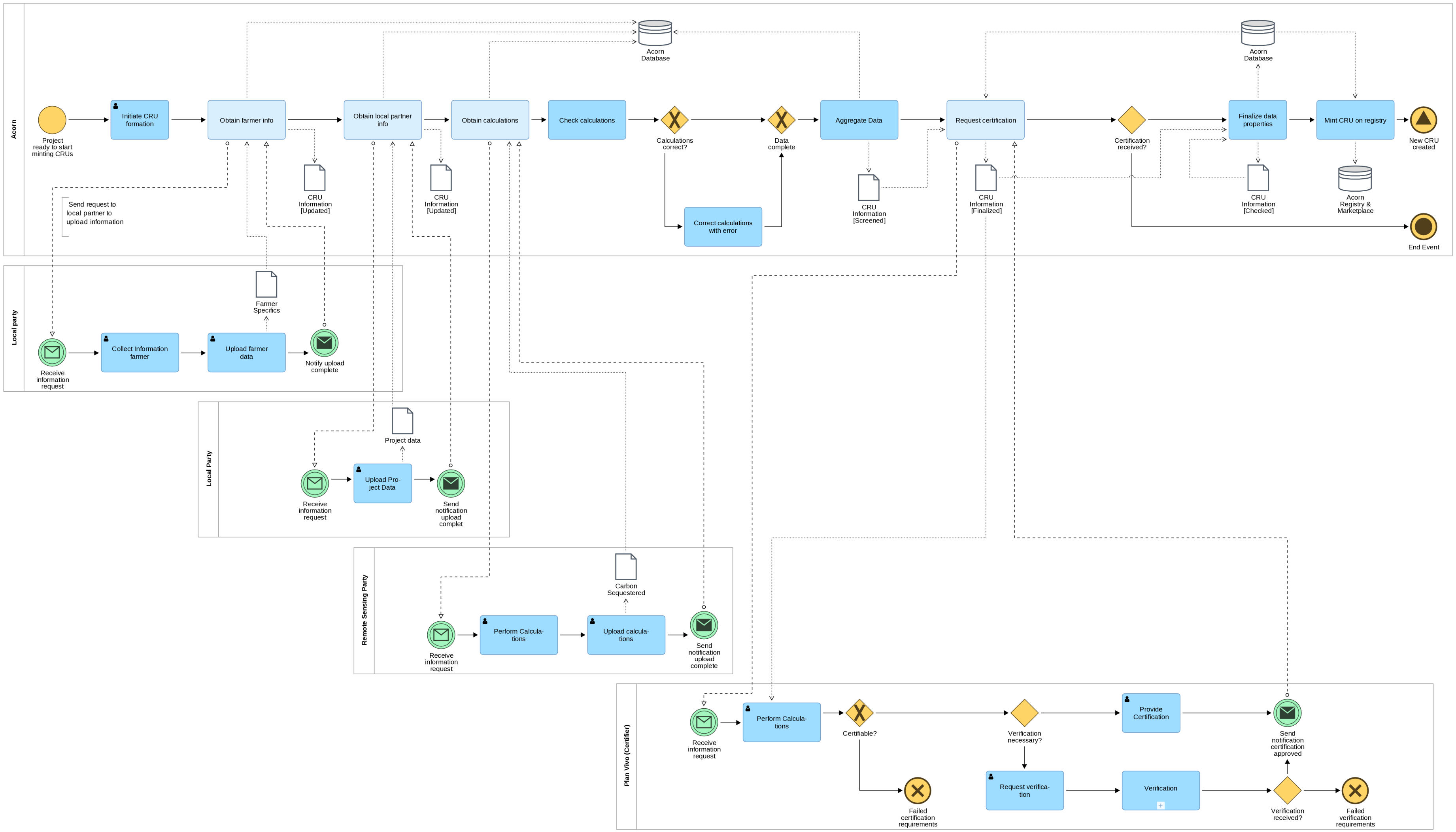

Figure C.1: Expanded Business process model of Acorn

D SCOPING INTERVIEW SUMMARY'S

D.1 SCOPING INTERVIEWS

This first interview discussed the potential options of doing research on double counting, while using Acorn as a case study and simultaneously discussed some key functions of Acorn.

Three options were discussed:

- if blockchain could be a suitable solution for Acorn's information management system.
- Looking into transparency, visibility and immutability and evaluating existing blockchains for these characteristics.
- How to optimize the information systems using blockchain, also considering the possibility of up-scaling.

Next, the issues of double counting and accounting are discussed. There is an issue with parties using blockchain and only uploading bulk data, from which it becomes very difficult to trace back the source of such data. Which is a problem since it undermines the value of the blockchain.

An even bigger issue discussed next, are the length, width and height proportions of carbon credits which are not uniform. The way a nationally determined contribution is documented is completely different from how a voluntary carbon credit is documented. So even if both are registered on the blockchain, they will not be one-on-one comparable to explore where the overlap is and if it is even happening. Consider looking into what is necessary to extract value from the blockchain. Scope 3 emission reduction also plays a role, but that is accounted for in a completely different manner. Rabobank Acorn decided to first focus on the supply of carbon credits, before implementing their proof of concept. This decision of postponing the application of blockchain was also dependent on issues such as double counting.

A relevant example of double counting was discussed: a government trying to boost agroforestry among smallholder farmers. They are supporting this by flyering and making trees available on every street corner. After a couple of years the government sees the increase in trees and report this in their NDC by saying x amount of villages times x CO2 captured which is very different from the length, width and height proportions Acorn uses. And it is not traceable to find out between these two programs if it was a bank to promote agroforestry investments or the government. Most likely it was both.

Another issue discussed were corresponding adjustments, regulation after COP26 but it is still unknown how these corresponding adjustments should be applied.

Next, the process of a third party verifier was discussed. Acorn collaborates with Plan Vivo and uses a third party, who does the objective verification since Plan Vivo receives a margin over the credits as certifier so there is a need for an objective party. Each year the new credits are based on the growth of the tree.

What is the key issue from which Rabobank Acorn came about? Rabobank has an extremely large gigantic international network of farmers. Rabobank saw that smallholder farmers are key for the food supply as well as the growing need for food. However therse farmers are hit hard by climate change, so then the question was how they could help farmers to become more resilient to climate change and the carbon market was one of the first ideas. The mechanisms allowed the money of the emitters to flow to the farmers. So the real issue, that Acorn wanted to solve, was these farmers not having access to the carbon market. Another issue solved by Acorn is that Agroforestry is one of the best ways for farmers to nurture better, more nutrient soil, become climate resistant and diversify income and food sources. So that is the real problem being solved in which the carbon market poses as the means.

Then current issues were discussed, the new technology of remote sensing, data quality (related to the smallholder farmers and ownership of parcels), lack of structure, malfunctioning communication in the bigger market. This led to a discussion on how Acorn is organized.

Acorn focuses on transparency, the more transparent they can be, the easier other parties can compare their practices with us. And so we can set the standard for the market, showing that it is possible to do so and how. Currently, Acorn checks in every country the regulations on carbon (NDCs and mitigation programs) and project history in the area. Acorn has the ease of very tangible evidence if similar projects were conducted before, essentially if there were trees on the plot of land, yes or no.

The issue surrounding double counting are not people with bad intentions but more so project developers who negatively influence the whole market, due to the accounting principles being very basal such that their undertakings. are technically correct.

Acorn's ledger is currently based on a crm tool, completely built to the requirements of Acorn. It is the only place that holds all the data, the platform can extract data to report all transactions linked to the correct data and is very transparent. This solution however does not offer the immutability of a blockchain currently.

With respect to stakeholders, Acorn collaborates with the local parties on one side and buyers on the other side. Microsoft supported Acorn from the beginning, helping Acorn to scale when starting. Acorn does not collaborate with national governments.

With respect to the blockchain, it is important to think about what data to upload on the blockchain since both satellite data, data of local partnerships could immensely increase the transaction data. Since some of these questions are left unanswered Acorn decided to not pursue a blockchain solution at this point.

E NETWORK FROM CASE STUDY

In this appendix the network structure from the data analysis of the case study is shown. The structure selected to depict the network was the an orthogonal tree. Figure E.1 shows the network as a whole, the readability in this picture is neglected. The aim is purely to illustrate the intricacies and vastness of the network.

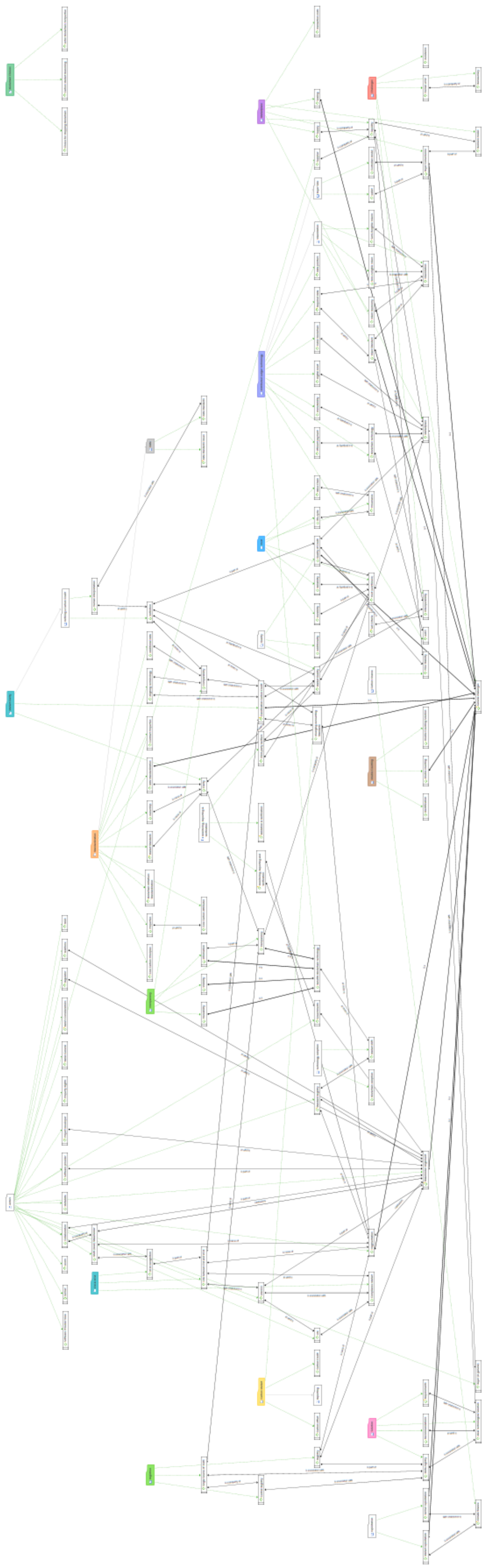

Figure E.1: Top layer of network, overview of actors

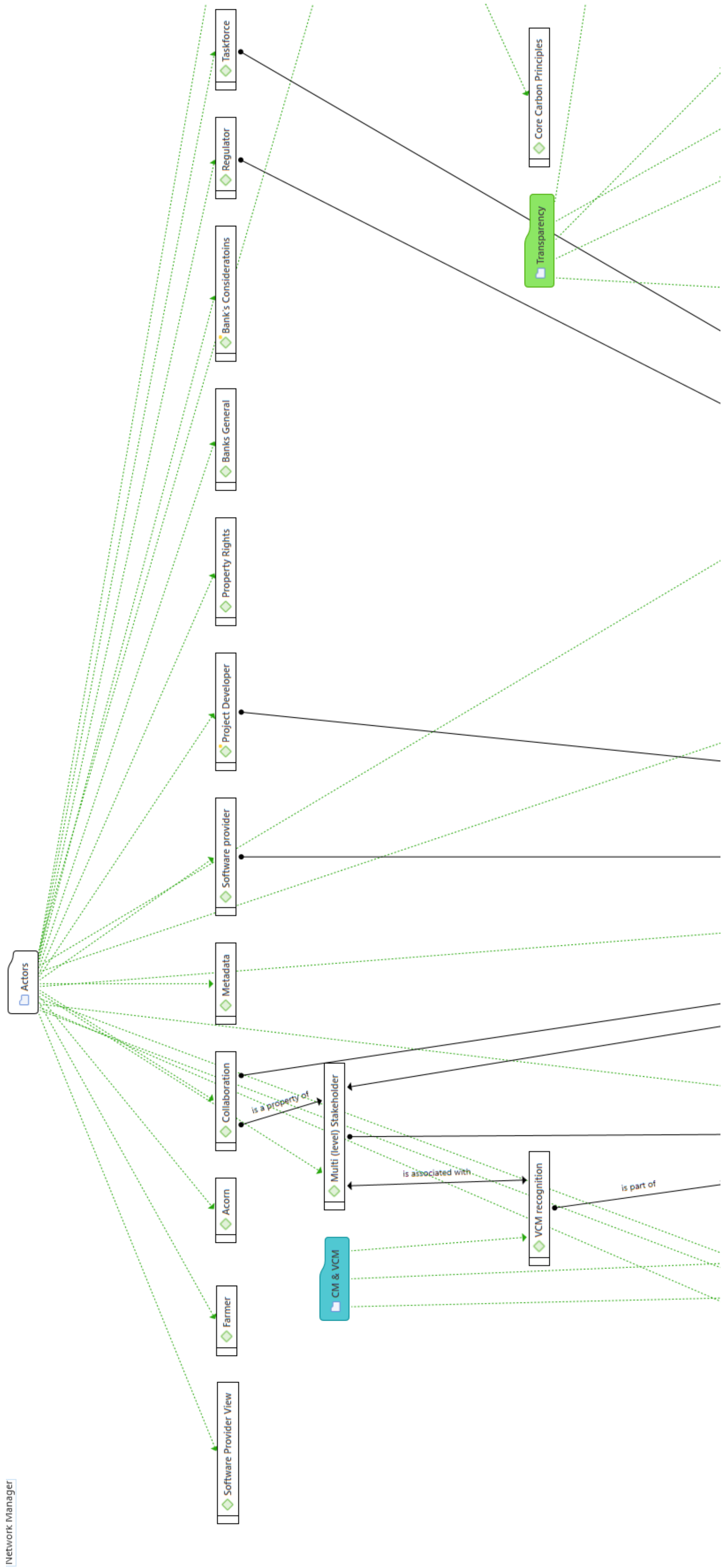

Figure E.2: Top left layer of network, overview of actors

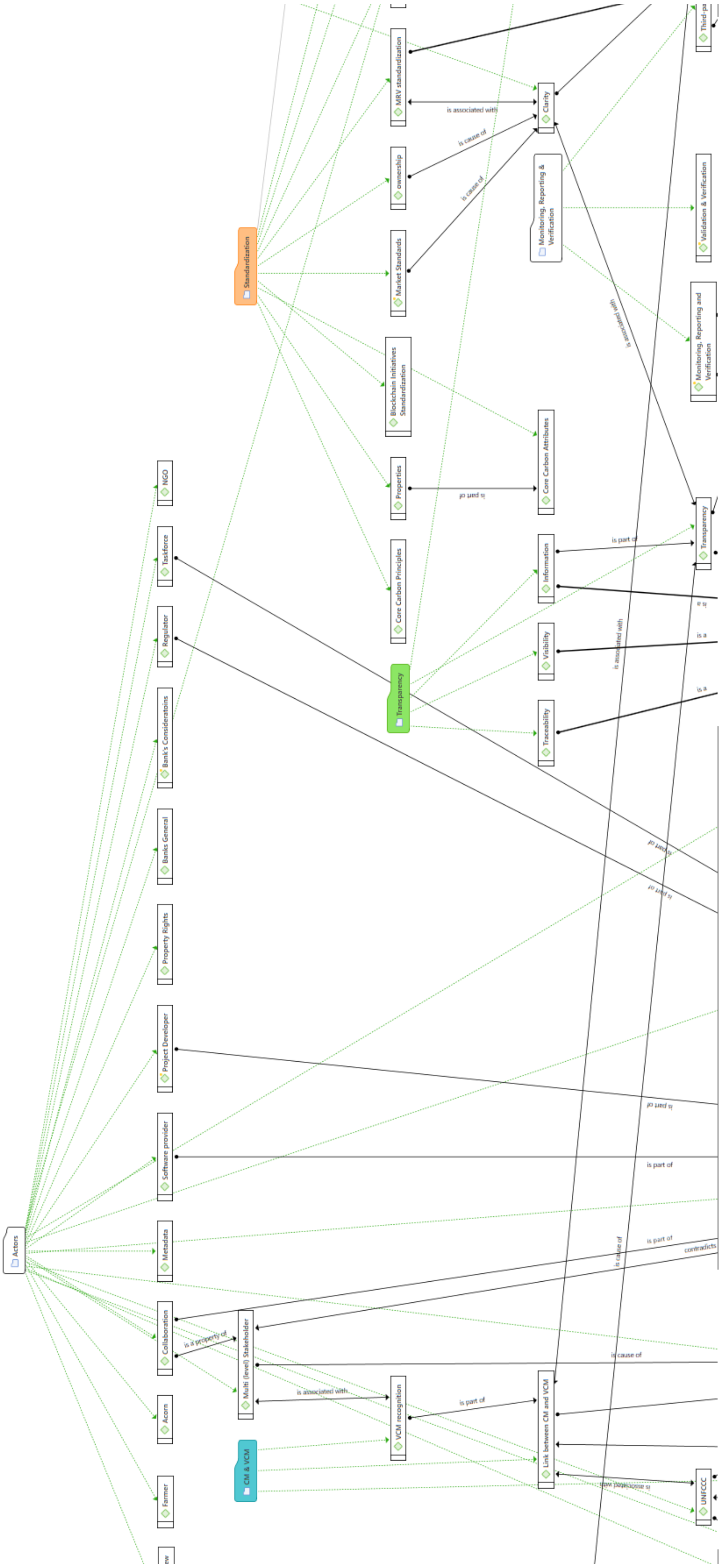

Figure E.3: Middle left layer of network, transparency

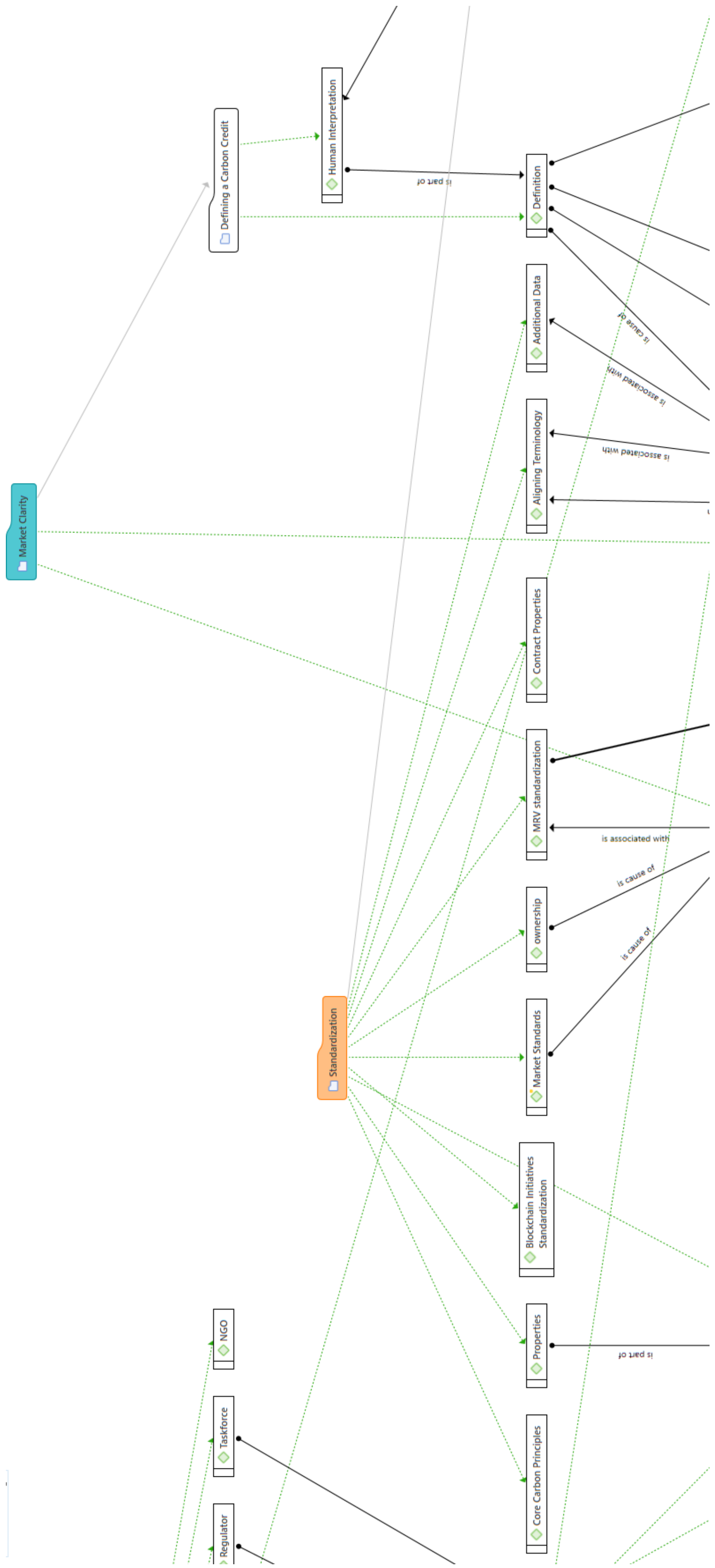

Figure E.4: Middle top layer of network, standardization

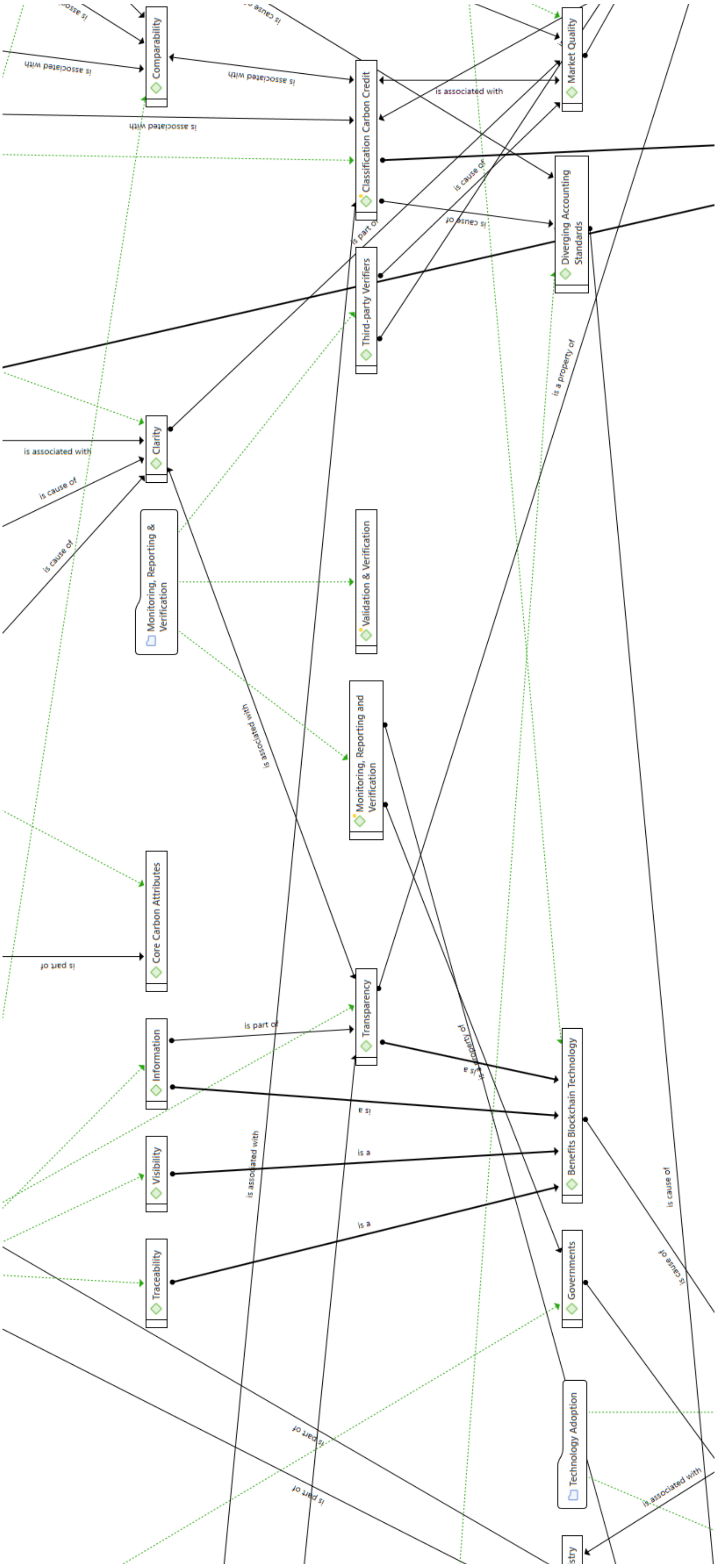

Figure E.5: Top layer of network, market clarity

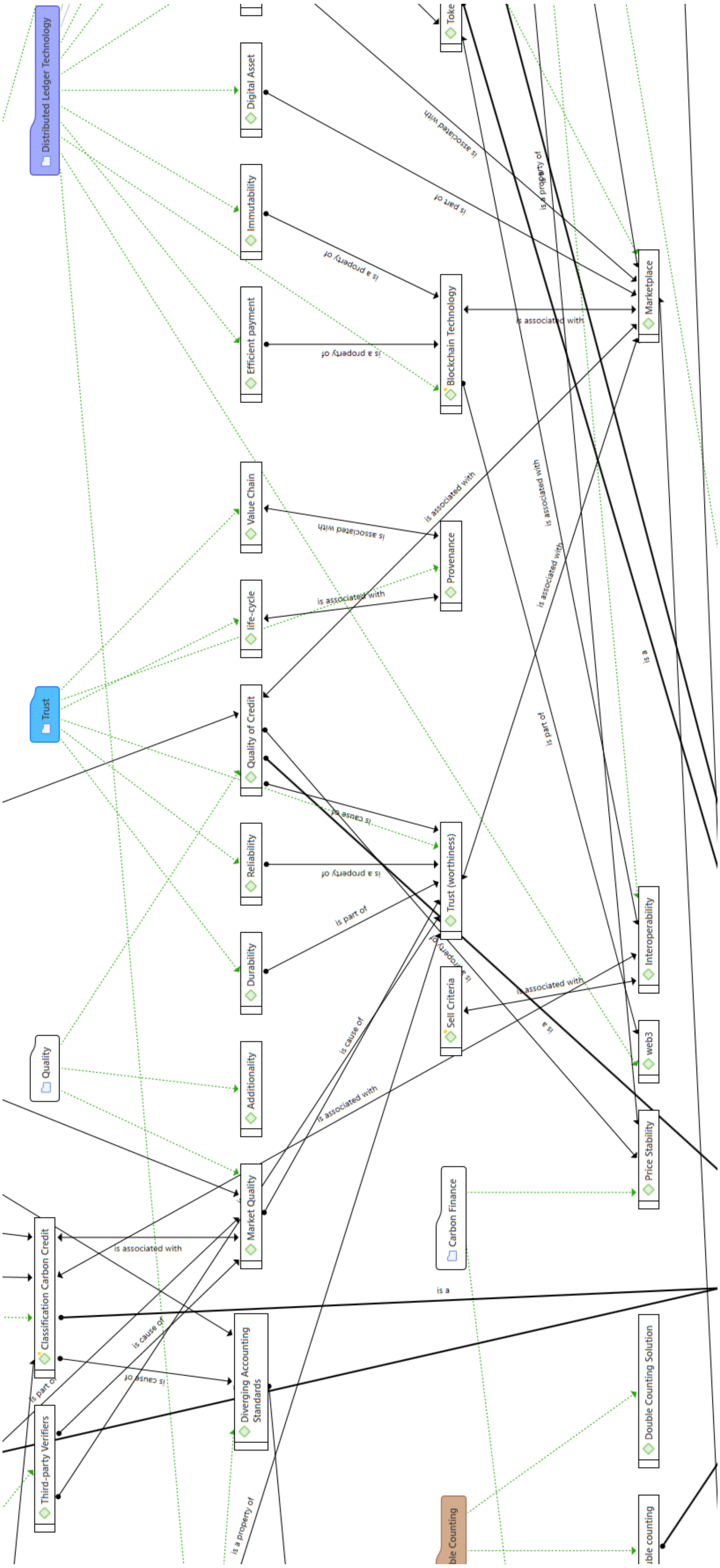

Figure E.6: Top right layer of network, market clarity

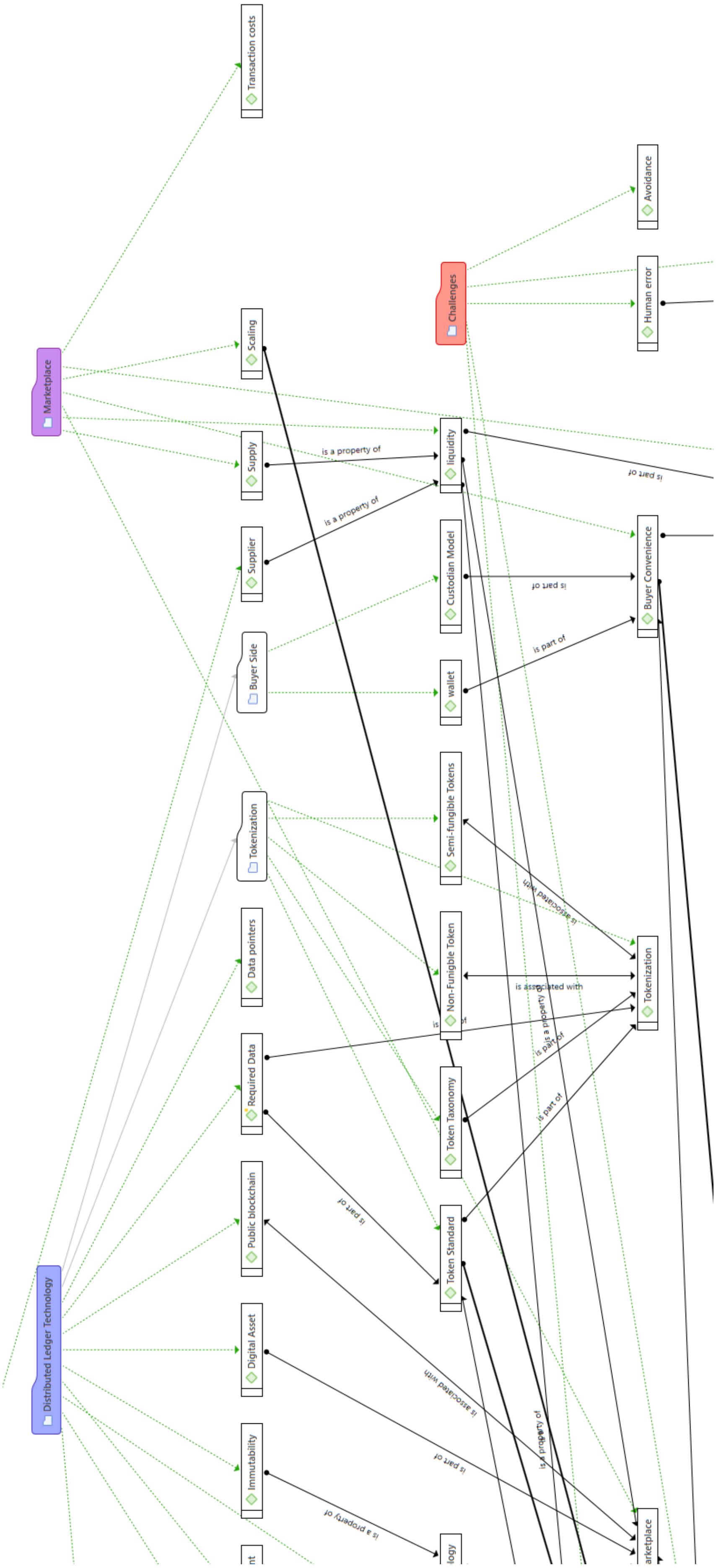

Figure E.7: Top right layer of network, blockchain technology

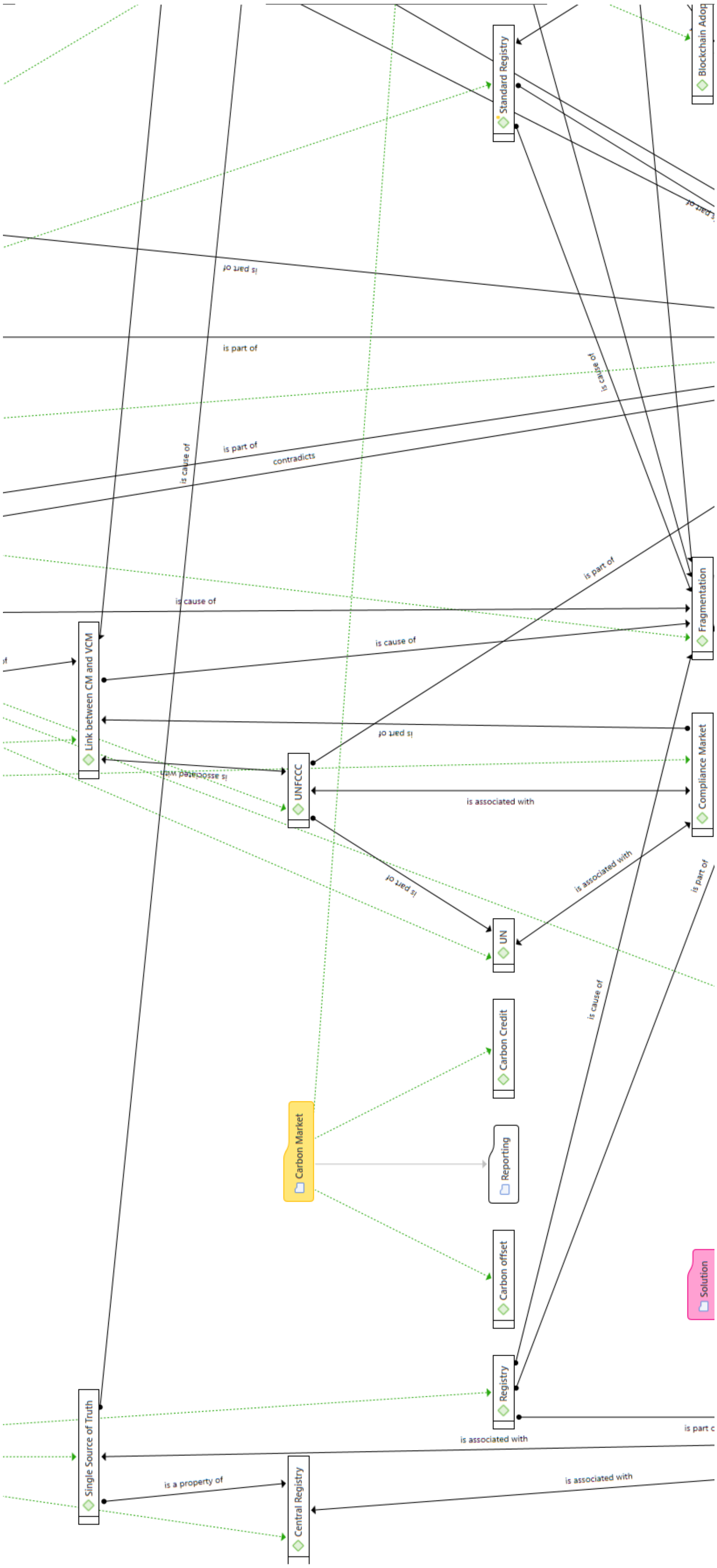

Figure E.8: Right layer of the network on blockchain technology

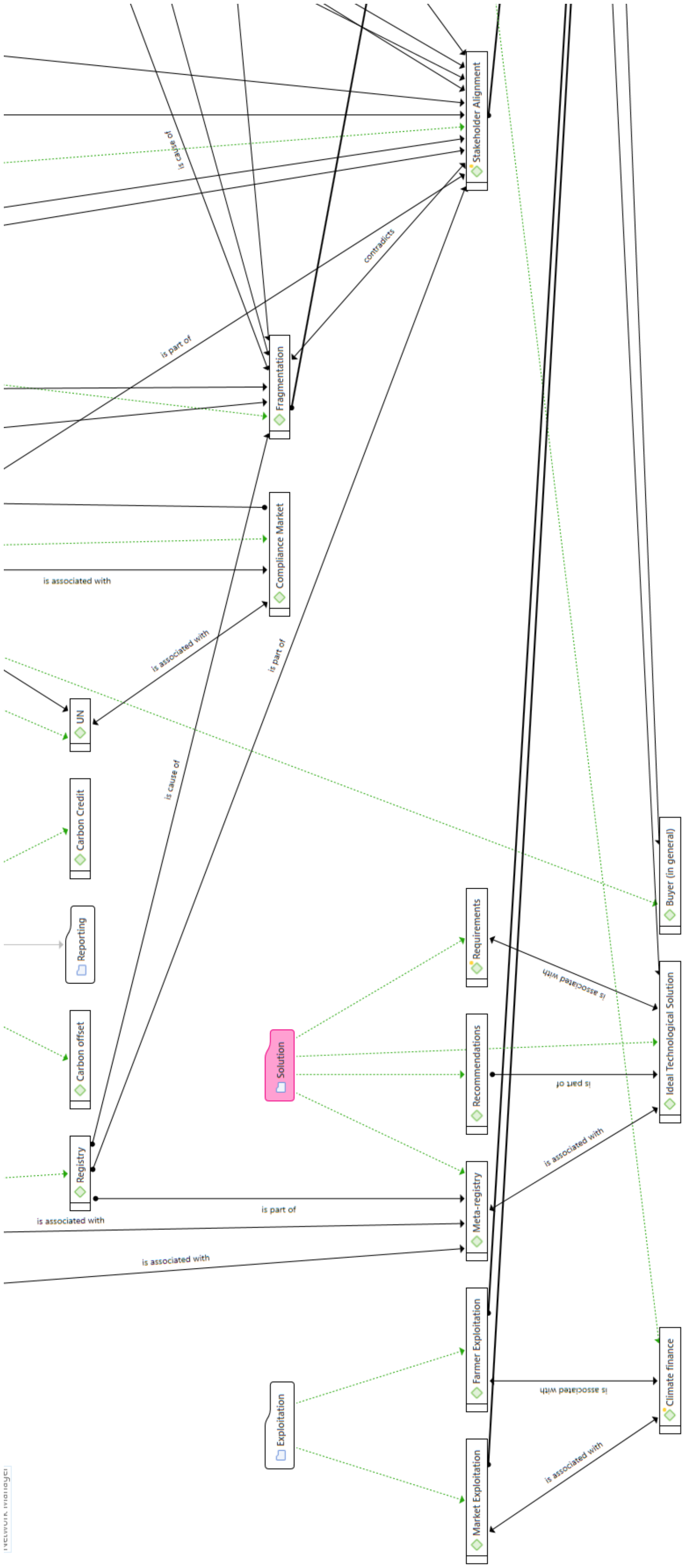

Figure E.9: Top middle of the network showing transparency

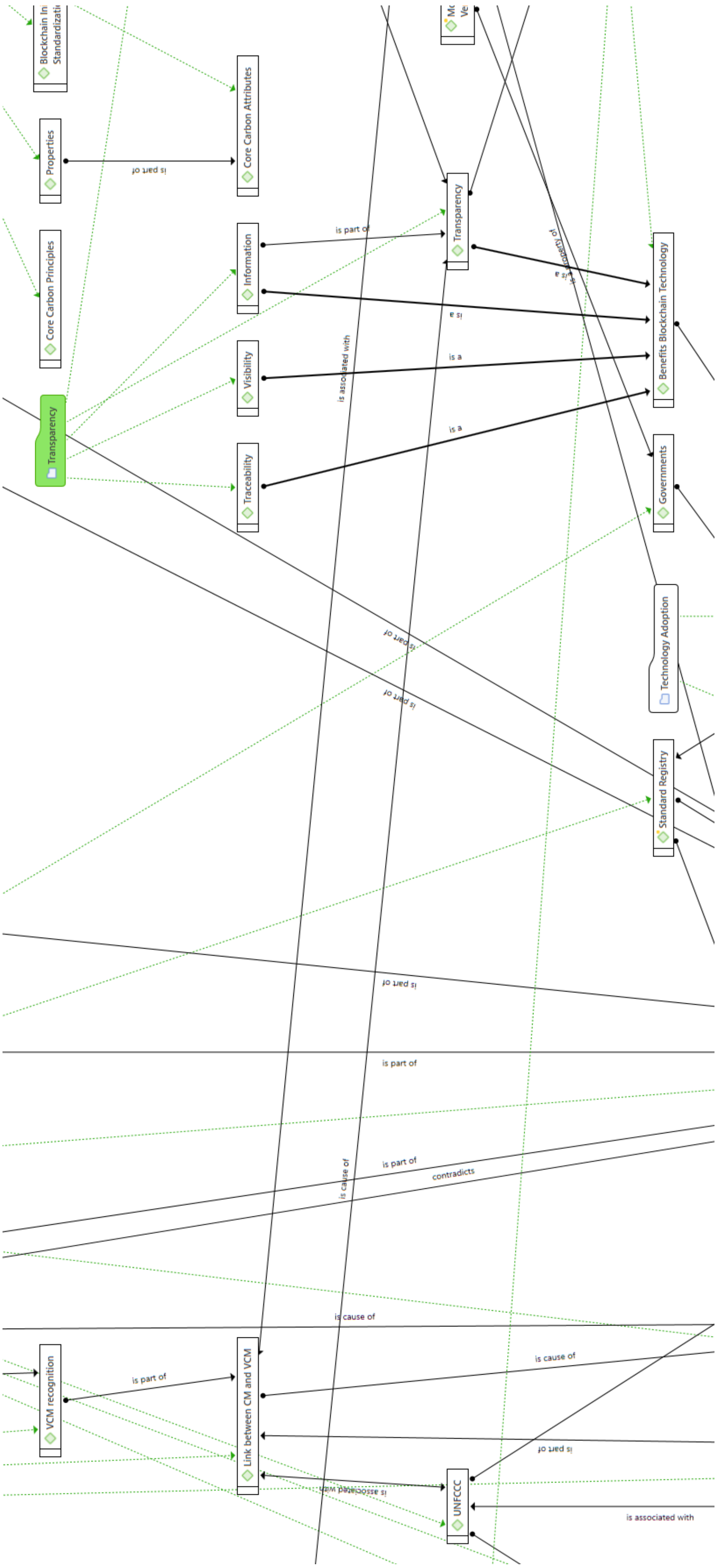

Figure E.10: Middle of the network

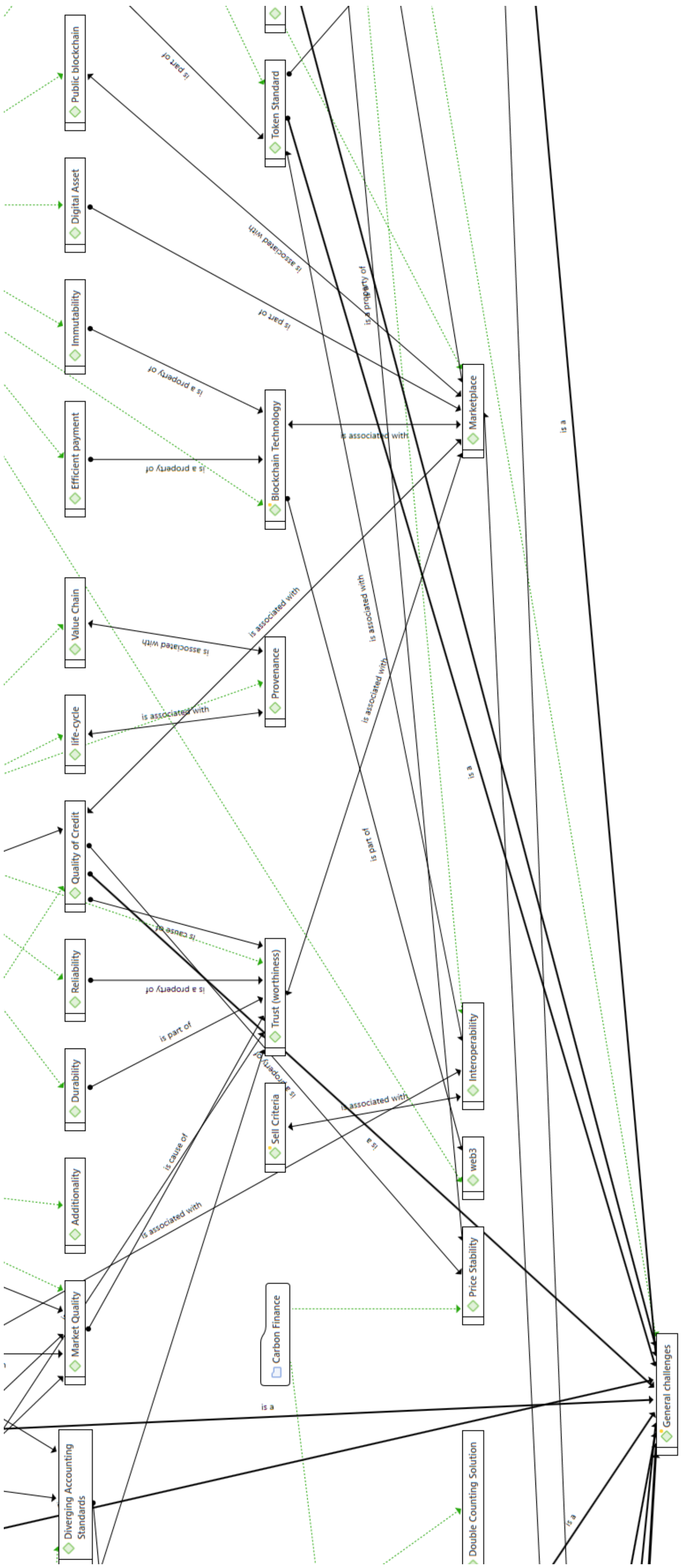

Figure E.11: Bottom layer of the network with general challenges

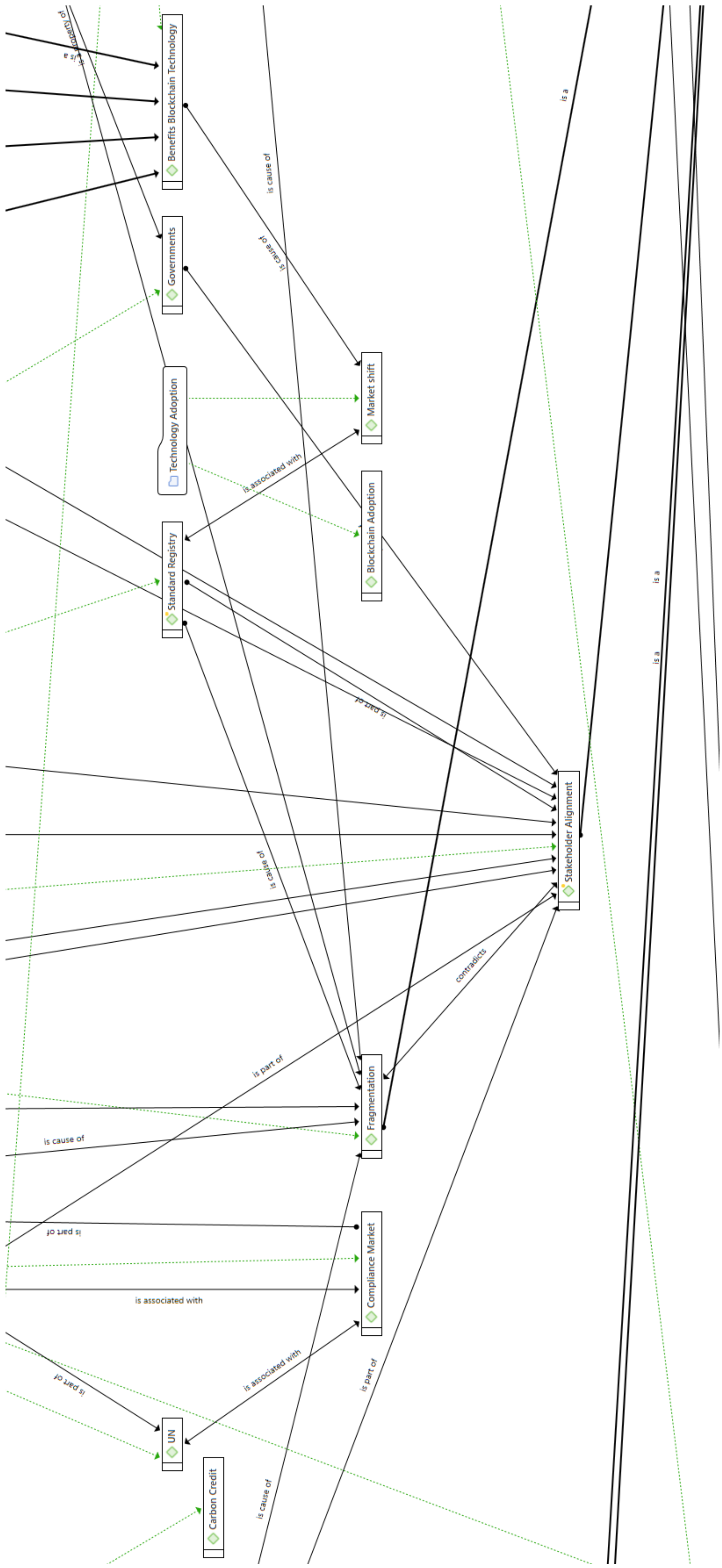

Figure E.12: Left Bottom of the framework focusing on stakeholder alignment

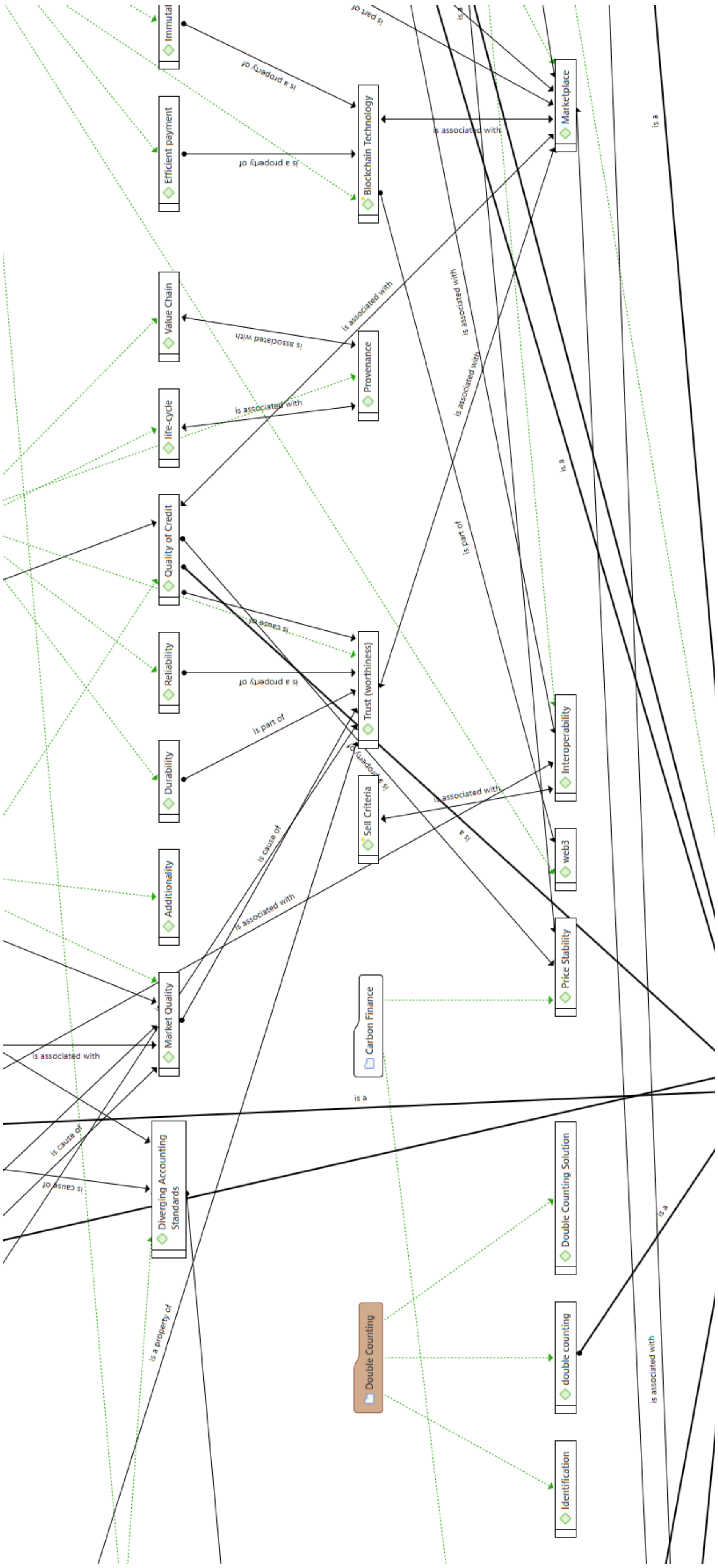

Figure E.13: Middle bottom view of the network

COLOPHON

This document was typeset using $\LaTeX$. The document layout was generated using the arsclassica package by Lorenzo Pantieri, which is an adaption of the original classicthesis package from André Miede.