Blocks and Credits: A Sustainability Lens on Blockchain Technology in Voluntary Carbon Markets

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Abstract: Society is dependent processes that emit greenhouse gases such as carbon dioxide into the atmosphere. The accumulation of these gases in the atmosphere prevents sunlight reflected from earth's surface to get to space thereby warming the earth and causing climate change. To prevent the effects of adverse climate change, the voluntary carbon market was designed to help buyers, individuals or organizations that cannot avoid emission in their process, purchase carbon credits from sellers, entities whose process prevent or avoid carbon emissions. The voluntary carbon market faces challenges like market fragmentation, opacity of records, and delayed processes due to layers of intermediation and double counting.

In an attempt to solve these challenges, blockchain, a ledger technology, has been applied by innovative organizations. This thesis researches the possible roles of trading carbon credits using blockchain based platforms in the voluntary carbon market. Furthermore, this thesis focuses secondarily on how the application could increase supply of carbon credits, influence commitment to net-zero, contribute to production of high-quality carbon credits, and promote fairness in carbon trading.

A conceptual framework based upon the Oxford Principles for Carbon Offsetting, Taskforce for Scaling the Voluntary Carbon Market (TSVCM), and the Sustainability Principles was used in this study. Seven organizations were investigated in this study through a first phase of interview and a second phase of survey.

The findings suggest that blockchain-enabled carbon trading has the potential to enable market growth, foster systems interactions and transition via information technology, and support opportunities for sustainability in the socio-ecological system. Blockchain also inherits the unsustainability of the overall tech and energy sectors wherein it operates. Weak governance systems off-chain from non-disclosures by market players also risk the market system on-chain to vulnerabilities. The authors conclude that trading carbon credit on blockchain-enabled platforms is a step in the right direction in terms of amplifying the contributions the voluntary carbon markets hold for cutting down carbon emissions. They also acknowledge that the blockchain-carbon credit application does not directly address upstream issues of carbon emission but serves as a mechanism to accelerate decarbonization.

Keywords: Carbon Trading, Voluntary Carbon Market, Blockchain Technology, TSVCM, Net-Zero, Sustainability Principles, Proof of Work, Proof of Stake

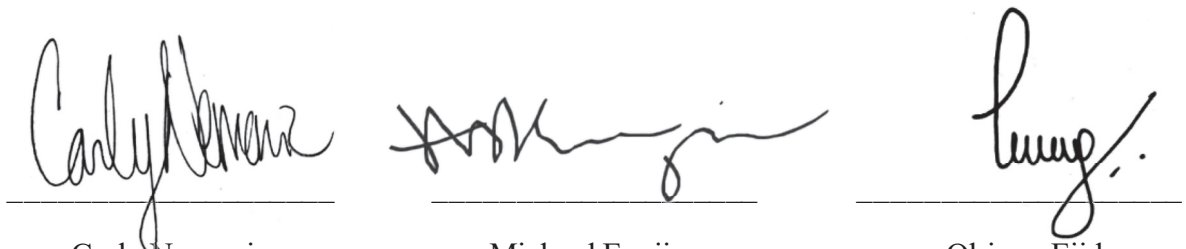
Statement of Contribution

The Blocks and Credits research is executed by thesis team Carly Nemanic (Bachelor of Science, Environmental Policy), Michael Enejison (Bachelor of Technology, Geology), and Obinna Ejide (Bachelor of Science, Biochemistry). From designing the research approach to data collection and analysis the entire group contributed their unique perspectives into this thesis, and the overall result comes from their shared mental model. Each members commitment to sustainability came together to form this dynamic team while bringing their strengths to the process.

Carly has been strong in bringing structure and clarity for the groups progression by keeping things organized and task-focused. She showed support to the group by summarizing what was happening with the timeline of work to do and contributing her professional background into standard procedures. Her professionality added a dependable element to the group and this thesis, being highly dependable and producing results.

Michael has been instrumental in keeping the team motivated by his high spirits and commitment to continue seeking alternative ways to tackle challenges as they popped up during the research. He was instrumental most especially during the design phase of the research and contributed his creative thinking skills to the research overall.

Obinna's risk management perspective from his professional experience helped in scoping the research within boundaries that helped the thesis team to achieve the aim of the research within the research constraints. On the same premise, he ensured the thesis had a balanced perspective by critiquing elements in systems during the discussion phase of the research.



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This thesis would not have been possible without the support of various groups who supported us or contributed to the research in some way.

Firstly, we would like to extend thanks to our primary advisor, Pierre Johnson, who gave us many hours of his time to discuss the direction of our work and contribute his knowledge of the technology field and its challenges. His insights were always rich with awareness, and his sustainability knowledge was the right mix of skepticism and recognition which helped keep our lens critical.

We would also like to thank the MSLS staff who have incubated us along the journey to becoming sustainability leaders and who have created a beautiful space for creating and learning. They have prepared us not only content wise but taught us how to work together harmoniously and respect the diversity of thought that appears when working in a new group.

Next, we would like to thank the individuals from the organizations interviewed who contributed their time to our research. They went out of their way to supply us with their valuable time and were eager to give us insight into the field, some even following up with us continuously to extend even more knowledge should we need it. For this we are extremely grateful, and we recognize progress would not have been made without them.

Our families, friends, and significant others also deserve a mention for showing their unwavering support for when we were mentally unavailable or needed consolation during this process.

Finally, we would like to acknowledge our appreciation of our fellow classmates who supported us with feedback and shared in this journey with us.

Executive Summary

Introduction

We live in a world that has numerous socio-ecological challenges. These challenges emanate from the systematic errors of societal design driving unsustainable use of resources, beginning at the industrial revolution, and they need to be addressed urgently. These collective problems and the obstacles society faces while transitioning to sustainability is called the sustainability challenge. Greenhouse gas (GHG) emissions from the current paradigm, primarily carbon dioxide (CO2) from fossil fuel production, has led to increased temperatures causing adverse climate change that manifest in form of drought, melting glaciers, food insecurity, and other socio-ecological challenges which threaten the prosperous era we know today.

To prevent adverse climate change, international consortiums led by United Nations initiatives have organized conferences such as The Kyoto Protocol, adopted in 1997, and The Paris Agreement in 2015. These conferences proposed market mechanisms to allow for higher ambition in carbon mitigation. In the voluntary carbon market (VCM), individuals or organizations can voluntarily offset carbon emissions by purchasing carbon credits created from projects that avoid or remove CO2 from the atmosphere. Blockchain is an immutable decentralized digital ledger used for recording information which has recently been proposed as a solution to help solve the accountability and transparency challenges of the VCM. Blockchain does this by providing secure digital record keeping of verified carbon credits as well as make trading accessible through tokenized carbon credits. Blockchain has been criticised for its energy consumption in its initial application in value exchange using digital currencies, though the technology is shifting to a less energy intensive process.

The Net-Zero Standard developed by the Science Based Targets Initiative (SBTi) suggests that corporations on the path to net-zero will need to neutralize residual GHG emissions. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change reports that avoiding the worst of climate change relies on preventing as many GHG emissions as possible as well as removing CO2 already in the atmosphere. Solutions within both documents include CO2 removal accessible through the VCM.

The main research question for this thesis is: "*What are possible roles of blockchain technology in carbon trading and voluntary carbon markets through a sustainability lens*?" The secondary research questions are: 1. Could carbon offsetting in the voluntary carbon credit markets via blockchain based technology potentially increase the supply of carbon credit projects? 2. Does the use of blockchain technology strengthen voluntary carbon buyers' commitment to net-zero? 3. Does the use of blockchain technology contribute to the production of high-quality carbon credits? 4. Does the use of blockchain technology promote fairness in carbon trading?

Conceptual Framework and Methods

Our conceptual framework to help answer our research questions were derived from The Oxford Offsetting Principles and the Taskforce for Scaling Voluntary Carbon Markets (TSVCM), complemented by the Sustainability Principles from the Framework for Strategic Sustainable Development to set boundary conditions for our sustainability lens. We followed a qualitative research strategy and used interviews as our research method to explore the niche of

blockchain within the voluntary carbon credit market space. Data was collected from seven collaborating organizations via semi-structured interviews conducted through an online video platform. Results from the interviews were analyzed using a coding structure that combined inductive and deductive analysis of the transcripts. Ethical considerations to the research included consent forms indicating the rights of the respondents and anonymizing organizations within the results. Limitations of the study included time constraints, possible bias in collaborating organization's responses, and the lack of longitudinal data on the topic.

Results

The results chapter is a summation of the data obtained from the interview process and the written survey, reported with a focus on the data necessary to answer the primary and secondary research questions through the sustainability lens of the 8SPs and supporting framework. The chapter is organized to reflect the themes of the framework, summarized into the major categories of Social, Environmental, Economic, Governance, and Infrastructure and Technology. The chapter goes on to discuss Deficiencies, Future, and Organization Specific sections which were identified and coded for within the results of the collected data.

Social
Highlights of this section includes the supplier and buyer specific benefits of the use of this technology. Improved user experience, open access for new stakeholders, and communications were specific buyer benefits mentioned here. Education on blockchain paradoxically appeared as buyer benefits and barrier to the adoption of blockchain. The respondents also expressed interest in developing strategic partnerships with government and private stakeholders.

Environmental
Highlights from this section include the summary of: nuances on quality credits relating to additionality, permanence, and co-benefits; emissions for blockchain, where organizations speak to the choice on using a more energy efficient PoS validation blockchain, mainly Polygon; and the urgency of the problem, where scaling up carbon removal, having multiple solutions, and the consideration that after society stops producing carbon there will still likely be a need for removal are the key discussion points.

Economic
Blockchain is seen as opening a window for new funding for carbon projects and the intention is to find direct funding from the old fossil-fuel based economy to an emerging regenerative economy. Tokenization is reported to help disintermediate and ease liquidation and influence activities on the demand and supply sides of the VCM.

Governance
Transparency in verification of carbon projects, accounting, trading, and retirement of carbon credits were highlighted as benefits of the use of blockchain. However, a disclosure gap of the carbon footprint of the users, pre-market entry on-chain, remains. Although a few respondents have developed their own carbon verification technology, they recognized that it will take time for on-chain protocols to establish the same level of credibility of legacy carbon registries.

Infrastructure and Technology
Six out of the seven organizations interviewed use the Polygon blockchain network reporting that this network is less energy intensive than other blockchain configurations.

Deficiencies
Deficiencies identified by respondents in the legacy carbon trading market include: mediation by contractors, manual characterization, analogue processes which leads to low incentive for developing offset projects, and an opacity of processes and records. Deficiencies identified by respondents in the blockchain applied market include: little or no standard in the system, the need for complementary technology, and the complexity and novelty of the blockchain domain.

Future
Responses most relevant to this thesis about the future of the blockchain and carbon credits application revolved around the topics of trading beyond carbon, supply chain innovation, disintermediation from brokers, and scaling up to an entirely on-chain carbon trading system.

Organization Specific
Features specific to the organizations interviewed are presented in Appendix A4.

Discussion

In this chapter, findings from the results are discussed. We present our analysis of the SP sustainability lens, followed by the secondary research questions and primary research question. Post-research reflections and finally recommendations for further research are also included.

SP Sustainability Lens
The current energy consumption of blockchain for this application nested in an unsustainable energy system does not align with the SPs but in the long term seeks to address this. It has the potential to become a leverage point for accelerating carbon removal as well as energy systems change through financing renewable energy projects, although it is important to note that a fully renewable system does not guarantee SP alignment. While trading carbon credits aims to do less harm, it cannot be overlooked that the application still relies on an energy system that, in some regions, are still heavily reliant on fossil fuels. Due to the ambiguous nature of the current energy regime and the implications of the blockchain system to be on an increasing curve of energy use, it is difficult to separate the blockchain system from the unsustainability of the current energy system. Except for supporting renewable energy credits, the carbon market does not apply upstream thinking to the systemic issues of carbon emissions at the source. The system does apply upstream thinking to creating a healthy environment, attempting to valuate things from ecosystem services that currently do not have a price associated with it. Ecological sustainability could be further enhanced through new market innovations discussed in the futures section of the results chapter, where interviewees referenced trading beyond carbon as a possibility to bring further value and variation to the market.

From the analysis of our results section, it was identified that the blockchain application for carbon credits does not address social sustainability as defined by the SPs. While there are positive contributions to the social SPs, blockchain's application to eliminate structural social obstacles within the systems that the use of this technology are nested are not addressed.

Could carbon offsetting in the voluntary carbon credit markets via blockchain based technology potentially increase the supply of carbon credit projects?
Combining blockchain technology with others such as satellite imaging for project verification could lead to lower costs for developing carbon offset projects, which could improve profitability and provide developers with more financial resources. Tokenization also enables liquidation which encourages trading, value appreciation, and the long-term incentive to

develop new carbon offset projects. Possible negative consequence for easy liquidation includes holders purchasing and keeping carbon credit tokens to create artificial scarcity. By holding these tokens, there is a halt in the resource flow needed to develop new projects.

Does the use of blockchain technology strengthen voluntary carbon buyers' commitment to Net-Zero?

The Science Based Targets Initiative's Corporate Net-Zero Standard defines corporate net-zero as deep emission cuts to zero and neutralizing any residual emissions at the net-zero target year and thereafter. If organizations are to purchase carbon credits to neutralize/offset their emissions, then they must find carbon credits that are accessible and accounted for. The application of blockchain with carbon credits does not automatically give buyers climate consciousness or proactiveness, however, if the organization prioritizes climate action and has follows the Net-Zero Standard to reach carbon neutrality, the blockchain application for trading carbon credits is an enabler of action. Driving the wheels of society towards net-zero, Blockchain for carbon trading can help meet global recommendations on carbon offsetting and trading such as those listed in the Oxford Offsetting Principles and the TSVCM.

Does the use of blockchain technology contribute to the production of high-quality carbon credits?

Due to the variable nature of the term 'high-quality' it is difficult to give a concrete answer regarding whether using blockchain within the carbon market contributes to the production of high-quality carbon credits. Applying blockchain technology to the market helps to retire older credits which are not up to current methodologies' standards. This is perceived to increase integrity of the current supply. From analyzing interviewee responses to the question regarding high-quality credits, it is believed that if a carbon credit is transparent in its methodologies and adheres to baseline standards, carbon credits will be acceptable in the market and then it is up to the buyer to determine what level of 'quality' meets their standards based off perceived benefits such as additionality, permanence, and co-benefits.

Does the use of blockchain technology promote fairness in carbon trading?

Tokenization of carbon credits in blockchain technology gives an incentive for participation in the carbon credit market, since tokenized carbon credits are liquid and active. The open feature of blockchain for all contributes to fairness. However, the permissionless use of blockchain infrastructure without due diligence pre-market entry on-chain may give room for unethical behaviours that could exploit the decentralized governance system or discredit environmental sustainability efforts of buyers when prioritizing sale of limited carbon credits. Most of the organizations interviewed use Verra and Gold Standard as carbon registries to source verified carbon credits. This portends the risk of carbon verification monopoly, which is a market competition for the blockchain entities if these registries go all blockchain. The carbon credit market system is based on a tenuous trust, so methodologies used by new carbon verification technologies should be tested by blockchain entities to reduce monopoly of carbon verification.

Primary Research Question

It has been identified by the authors the roles that blockchain plays to address the sustainability challenge are: enabling markets, transition in the information and technology sector, and supporting opportunities for change in the socio-ecological system.

Ease of market access, likely revenue increase for project developers from disintermediation, and increased market liquidity from tokenization are benefits blockchain brings to the carbon market. These could help to finance carbon removal or avoidance project development.

Governance systems off-chain, market consonance on the definition of quality credits, and new carbon verification methodologies are additional factors required for blockchain to help VCMs achieve scale necessary to significantly impact the sustainability challenge.

Other technology infrastructures enabled by blockchain have the potential to enable further innovation needed to address the urgency of climate change and improve interaction between unlinked systems that can benefit from interconnectedness. Carbon trading can be viewed as a transitioning strategy for decarbonisation, and layering blockchain with carbon credits has the potential to accelerate VCMs towards reaching Net-Zero.

While the current blockchain system relies on energy which inherently comes with the problems associated with the fossil fuel reliant energy system, it has the potential to become a leverage point for accelerating carbon removal and avoidance projects as well as energy systems change through financing renewable energy projects. The authors see that blockchain has the potential to support the ease of sale of projects which support ecosystem health and promote nature-based solutions, thereby supporting the health of the socio-ecological system.

Post Research Reflection and Recommendations
Aspects of the study which in hindsight could have yielded better results are: designing the survey questions into the interview sessions for a more robust response, limiting the study to the primary research question given time constraints, and including legacy carbon registries in our scope of study for a more complete systems perspective on the VCM.

Other reflections and recommendations include: additionality and ecosystems benefit could serve as baseline quality metrics to establish a reference price for carbon credits, there is a need for more standardized verification bodies in VCMs, public education about blockchain and the systems it nested in could help increase communications on the sustainability challenge, there is a need for strategic partnerships among blockchain entities and between allied sectors. For further research, quality carbon credits and pricing of carbon credits could be explored, in addition to exploring the secondary research questions in this study as stand-alone topics.

Conclusion

The application of blockchain with carbon credits has the potential to contribute to socio-ecological sustainability by enabling scale and access to carbon removal or avoidance projects. It also provides a platform upon which other environmental innovations could thrive. While the application seeks to reduce carbon in the atmosphere, it inherits the unsustainability of the overall tech and energy sectors upon which it operates. Weak governance systems off-chain from non-disclosures by market players also risk the market system on-chain to vulnerabilities.

Tokenizing carbon credits increases liquidity, helps eliminate middlemen, and likely increases revenue for project developers. By influencing markets, blockchain could help drive up the price of carbon credits and help define a minimum quality for carbon credit pricing. Education about the application and the systems it is nested in is recommended as the phenomenon brings awareness about sustainability to technology professionals and enthusiasts. The authors consider blockchain-carbon credit application as having a contribution in the voluntary carbon market via solving market frictions in the transition towards a sustainable society but is not a silver bullet for solving systemic issues in technology, energy, and climate change.

Glossary

Blockchain	Blockchain is a digital ledger comprised of unchangeable, digitally recorded data in segments or 'blocks'. Each block is 'chained' to the next block using a cryptographic signature.
Carbon Credit	A permit that accounts for the equivalent of one tonne of carbon dioxide or the equivalent in other greenhouse gases.
Framework for Strategic Sustainable Development (FSSD)	A structured approach to sustainability planning using the 8SPs as boundary conditions for sustainability (Broman and Robèrt 2017, 20).
Greenhouse Gas (GHG)	Gases which absorb and re-emit infrared radiation, thereby trapping it in Earth's atmosphere. Includes carbon dioxide (CO2) (Science Based Targets Initiative 2022).
ICROA Code of Best Practice principles	State that a carbon credit must be: Real, Measurable, Permanent, Independently Verified, Additional, and Unique (ICROA 2021).
Intergovernmental Panel on Climate Change (IPCC)	United Nations body for assessing the science related to climate change.
International Carbon Reduction and Offset Alliance (ICROA)	Organization which attempts to define and promote best practice in the financing of high-quality emissions reductions and use of carbon credits
Internet of Things (IOT)	The network of physical objects or things that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet.
Nature-Based Solutions	Actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (Cohen-Shacham et al., 2016).
Net-Zero	Setting corporate net-zero targets aligned with meeting societal climate goals means (1) achieving a scale of value chain emissions reductions consistent with the depth of abatement at the point of reaching global net-zero in 1.5˚C pathways and (2) neutralizing the impact of any residual emissions by permanently removing an equivalent volume of CO2 (Science Based Targets Initiative 2022).
Net-Zero Standard	SBTi designed standard meant to provide a standardized and robust approach for corporations to set net-zero targets which are aligned with climate science.

Proof of Stake (PoS)	A consensus mechanism in which an individual validates transactions or blocks. Validators "stake" their cryptocurrency on transactions (blocks) they wish to validate, in order to receive a reward.
Proof of Work (PoW)	A consensus mechanism in which each block validation is competed for in a race to validate in order to obtain the reward. PoW is significantly more energy-intensive than PoS.
REDD+ (Reducing Emissions from Deforestation and Forest Degradation)	Carbon credit aimed to make forests more valuable standing than cut down, the plus stands for the role of conservation (Howson et al. 2019).
Science Based Target Initiative (SBTi)	Partnership between CDP, the United Nations Global Compact, World Resources Institute and the World Wide Fund for Nature which aims to mobilize the private sector to take the lead on urgent climate action.
Smart Contracts	Automated action programs whose terms are recorded in computer code which can be executed once a set of conditions is met.
Sustainability Challenge	As degradation of our socio-ecological system systematically increases, the need to find solutions grows more urgent (Robèrt et al. 2015, 13).
Sustainability Principles (8SPs)	The eight basic principles for a sustainable society in the biosphere, underpinned by scientific laws and knowledge (Broman and Robèrt 2017, 22).
Token	A digital representation of an asset.
Voluntary Carbon Market (VCM)	A voluntary market where organizations or individuals buy and sell carbon credits that represent certified removals or reductions of greenhouse gases in the atmosphere.
Web3	Web3, or Web 3.0, are terms for "the decentralized web" broadly refer to the blockchain and decentralized technology system.

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1 Introduction

1.1 The Sustainability Challenge

Modern human society was built upon the paradigm of extracting natural resources with little regard for how this extraction affects the ecological system. The impact of humans' activities dominating the natural environment and causing mass extinctions has been so severe that scientists describe the current geological epoch as the "Anthropocene" era (Crutzen 2006). This systemic disregard must be addressed from a systems perspective if society is to be sustainable. The systematic errors of societal design that are driving humans' unsustainable effects on the socio-ecological system, and the serious obstacles to fixing those errors, combine to form sustainability challenge (Robèrt et al. 2019, 9).

One of the most critical sustainability challenges the socio-ecological system faces is climate change. Exploitation of the natural world and greenhouse gas (GHG) emissions have increased at unprecedented speeds beginning during the industrial revolution. GHG gases, primarily CO2, are emitted from industrial activities. They remain in the atmosphere, absorbing sunlight and solar radiation that bounced off earth's surface. By absorbing sunlight and solar radiation and preventing them from escaping to space, it makes the earth hotter. An increase of 1.5°C in global average temperature above pre-industrial levels is regarded as the limit for what Earth can take to mitigate the worst of climate change. Impacts at 1.5°C and beyond may include the effects of changing hazards, such as the frequency and intensity of heat waves, food scarcity, and other events which could negatively impact sustainable development goals (Allen et al. 2018, 68).

To cut down CO2 emissions, international consortiums such as the Kyoto Protocol in 1997 and Paris agreement in 2015 proposed market-based mechanisms. One of such mechanisms is the voluntary carbon market (VCM).

1.2 Carbon offsetting and the voluntary carbon market

Carbon offsetting means that individuals or organizations that emit CO2 are able purchase carbon credits from projects which avoid or reduce carbon emissions. In the VCM, a buyer purchases carbon credits to offset their carbon emissions.

The evolution of VCM is well captured in the timeline developed by the International Carbon Reduction and Offset Alliance. The voluntary carbon market has undergone evolution via three phases over time: early market formation and innovation, consolidation and strengthening, and mainstream adoption. The 1990s to 2007 constituted the pioneering of new concepts and the development of rules, as well as the establishment of tools and standards. The launch of the Gold Standard, a voluntary carbon offset program focused on progressing the United Nation's Sustainable Development Goals (SDGs) and ensuring that project's benefit their neighbouring communities, happened in this phase. From 2008 to 2016, best practices evolved, and the private sector was engaged in discussions giving rise to new project types and methodologies that had greater geographic diversity and increased links to sustainable development. The first REDD+ credits were issued in this phase and the Ecosystem Marketplace report showed that offsets were part of comprehensive corporate climate strategies. The mainstream phase, from 2017 to 2020, saw market growth and corporate awareness of this market, as well as the validation of VCM standards and innovations by compliance systems. The launch of Gold

Standards for the Global Goals was witnessed in this phase, and research showed Fortune Global 500 companies were increasing climate actions (International Carbon Reduction and Offset Alliance 2020).

VCMs offer opportunities for companies to meet voluntary corporate climate targets in support of the low-carbon transition (Rosales et al. 2021). Researchers have discussed why companies choose to use voluntary carbon offsets, and a report from Ecosystem Marketplace and Business for Social Responsibility (2008) highlights some of the potential reasons:

- Meeting internally set targets for reduced GHG emissions, when reducing their own emissions within the company, are no longer sufficient or cost-effective.
- Motivate and create internal incentives for change within the company.
- Gain experience in the carbon market to have the opportunity to influence and be prepared for any legal requirements.
- Improve their own brand by creating added value and attract investors by meeting competition on the market.

Voluntary carbon credits also support investment in innovation needed to reduce the cost of emerging climate technologies. About USD 4 trillion annually will be needed globally till 2050 to achieve a 1.5°C target across various sectors. Additionally, voluntary carbon markets that are scaled up would facilitate the mobilization of capital to the Global South, where the potential for economical nature-based, emissions-reduction projects is most probable (Kapnick 2021; Taskforce on Scaling Voluntary Carbon Markets 2021).

It is possible for communities to benefit from carbon trading if the practice builds climate resilience through restoration, establishes regenerative agriculture practices, and creates welfare for the people living in these areas. One of such instances is the Reduce Emissions from Deforestation and Forest Degradation (REDD+) carbon credits. REDD+ credits support countries' efforts to foster conservation, sustainable management of forests, and enhancement of forest carbon stocks. These types of credits provide economic incentives to make forests more valuable standing than cut down, however they have been criticized for lack of public inequitable distribution of project costs and benefits and failure to secure rights for forest dependent and indigenous communities (Howson et al. 2019). A few other types of carbon credits include calculations of carbon sequestered from regenerative agriculture practices, nature-based solutions, and emissions avoided from renewable energy credits.

The International Carbon Reduction and Offset Alliance is generally recognized as the standard for what a carbon credit should be. The key principles in the ICROA Code of Best Practice are that carbon credits validated and verified by permitted Standards must be: Real, Measurable, Permanent, Independently Verified, Additional, and Unique (ICROA 2021). Two of the most highly regarded verification bodies, Verra and Gold Standard, are endorsed by ICROA.

1.3 Challenges of the voluntary carbon market and carbon trading

One issue highlighted in literature on carbon projects is the widespread efforts of carbon accounting and regulations across organizational fields - each prioritizing different goals. A representative carbon accounting system must be based on measurement that is materially accurate, consistent across treatment of transactions, timely, and incorporates high quality data

while capturing uncertainty (Rosales et al. 2021). Other challenges of the voluntary carbon credit market include market fragmentation and complexity, unreliability of carbon credits, and limited pricing data for fair competition. High-quality carbon credits are also scarce, and this is because accounting and verification methodologies vary and credits' co-benefits (for instance, community socio-economic, and environmental benefits) are seldom well-defined (Blaufelder et al. 2021). Renewable energy credits and carbon credit systems have incentivized clean energy and environmental projects, but they still suffer from inefficient accounting and management procedures (Ashely and Johnson 2018). Research shows that the voluntary carbon market is yet to align itself with the recent legal architecture of the Paris Agreement in a credible and legitimate way; there is a discrepancy between the demand for carbon credits and the ability of the established certification schemes to supply credits legitimately and in a way that supports the Paris Agreement (Kreibich and Hermwille 2021).

1.4 Blockchain technology in carbon trading and the voluntary carbon market

A blockchain is a decentralized digital ledger used for recording information. Every change to the system for each block, or new transaction, is recorded, added to the chain, and made publicly available for review. The system is decentralized, meaning that the information is distributed across computers (nodes) around the world, and there is no singular authority to control it. Blockchain is a foundational technology and is inherently unbiased in its structure, however traditional uses of crypto assets have been questioned for their social benefit, often being associated with consumer risks and criminal intent such as money laundering (Thedéen and Risinger 2021). Despite this, blockchain has the potential to create new structures for our economic and social systems and has applications for data storage, voting, government systems, logistics, currency exchange, and more (Iansiti and Lakhani 2017). Blockchain technology offers several desirable properties: individual reporting errors are eliminated through decentralized replication and distribution of data; transparent data is shared directly among all nodes which prevents data manipulation and monopoly; information on blockchain is tamper-proof and traceable; and it is more resistant to technical failures and malicious attacks (Zhao and Chan 2020, 1).

The application of blockchain with carbon credits is an attempt to trade tokenized credits on an immutable decentralized ledger. By tokenizing carbon credits on blockchain networks, the problems associated with involving third parties such as brokers can be avoided. Backed by blockchain technology, carbon markets could have an accounting system in place to reduce the potential for fraud and nearly eliminate the possibility of counterfeiting (Leonhard 2017, 28).

Chen, 2018, identified five different utility applications of blockchain for sustainable development in the following areas: electricity markets, green token finance, the new economy, carbon offset trading, and carbon stocktaking. These five areas impact the wider field of sustainable development but two of them zoom closer to the focus of this study. They include carbon stocktaking - keeping a record of carbon credits on a decentralized ledger, and carbon offset trading - selling carbon credits to organizations or individuals that wish to offset their footprint using tokens.

Through the convergence of blockchain and carbon credits comes a need for more case-specific exposition and that blockchain-based conversation has so far lacked the authoritative scholarly analysis it deserves, suggesting the need for a practical critique for understanding the

particularities of each intervention (Howson et al. 2019). Some start-ups have begun using blockchain technology to avoid double spending of carbon credits and create a competitive market condition for influencing their price. To spend carbon credits, a complementary token can be traded securely on a blockchain ledger.

Whilst the tokenization of carbon credits can lead to more accountability, there are concerns that it may consume enough energy to make the application counterproductive to its intention. After backlashes from environmental groups about the carbon footprint of blockchain projects, Ethereum, which is a forefront blockchain project, has planned to migrating from proof of work (PoW) to proof of stake (PoS) (Ethereum 2022). The first application of blockchain was introduced in 2008 with the creation of the cryptocurrency called Bitcoin which operated on the foundational process of PoW to validate a blockchain transaction. PoW is energy intensive because miners worldwide are in a competition to solve cryptographic puzzles and be rewarded with cryptocurrencies to validate each transaction (block) and add it to the list (chain). Validators are competing amongst themselves to validate transactions to get a crypto reward and get paid for their contribution, but this creates an arms race within the network multiple times over. A new design derived from this original transaction verification system was introduced in 2012, the PoS (Dimitri 2021). PoS consumes significantly less energy. It uses a different consensus algorithm so instead of racing to solve the puzzle, validators 'stake' a certain amount of cryptocurrency and the technology selects one processor to complete the work in exchange for a cut of the transaction fees.

The Crypto Carbon Ratings Institute released a paper January 2022 titled 'Energy Efficiency and Carbon Footprint of PoS Blockchain Protocols' which details the current state of the technology. The paper summarizes the fact that electricity consumption of the PoW system remains significant, but that blockchain networks based on alternative consensus mechanisms such as PoS consume significantly less energy (Gallersdörfer, Klaaßen, and Stoll 2022, 3). Through their methodology they calculate yearly electricity consumption of PoS networks range from 70,000 kWh to roughly 1,900,000 kWh and concluded that: "In comparison to the decentralized cryptocurrency Bitcoin, PoS networks consume less than 0.001 % of the Bitcoin network assuming 89.78 TWh on the 21st of August 2021 (CBECI, 2021). Bitcoin consumes much more electricity than any Proof of Stake system due to its Proof of Work consensus mechanism, resulting in the deployment of energy-intensive hardware," (Gallersdörfer, Klaaßen, and Stoll 2022, 21).

1.5 Transitioning systems and accelerating decarbonization

A reason why sustainability remains a challenging topic is because society within the biosphere is a complex dynamic system. Solutions which focus on downstream problem solving, where only symptoms of unsustainability are addressed, have been proposed as solutions when they continue to allow the root causes to perpetuate an unsustainable society. This idea that the whole can be understood by analyzing the individual parts it consists of is called the reductionist approach. In contrast to the reductionist approach is systems thinking, which describes the organized study of systems, their feedbacks, and their behavior as a whole (Robèrt et al. 2019, 6). The use of a systems thinking perspective is a holistic approach taken to analysis that considers how a systems parts interrelate and how systems work within the context of the larger socio-ecological system.

Interventions in society need to move towards sustainability while still being aware of upstream obstacles. As society transitions to sustainability, tools which support innovations and new solutions for the transition are needed to adopt a strategic perspective in a timely manner reflecting the urgency of the sustainability challenge. There is increasing pressure on businesses and consumers to reduce their carbon footprint and transition from an economy of exploitation to a sustainable and regenerative one. As individuals and organizations wake up to the urgency of the problem, they are looking for solutions which enable a high quality of life while reducing environmental impact.

Carbon trading is a transitioning phenomenon that can be explained using the Three Horizons framework, where the objective of the transition is to shift society into a new sustainable future. The Three Horizons framework was created by Bill Sharpe, an expert in futures techniques, along with other members of the International Futures Forum.

Figure 1-1 is a visual representation of the three horizons, or possible futures. Horizon 1 (H1) is 'business as usual' and represents if nothing changes in unsustainable practices. Horizon 3 (H3) represents the 'emerging future' or where it would be desirable to be. Finally, Horizon 2 (H2) represents 'disruptive innovation' and shows the change from the established pattern of H1 to the emergence of the new pattern of H3 via the transition activity. The three horizons exist continuously, and the framework highlights the importance of acting now to change the trajectory of the future. This is a constantly adapting process, and as H3 is approached, it transforms in response to other systemic change. By the time it is realized, H3 will have become H1, and new challenges must be faced that require again a perspective of how actions are leading to a sustainable future. The climb towards sustainability will have many iterations of these processes, summiting H3 only to recognize a new H1 with unpredictable challenges.

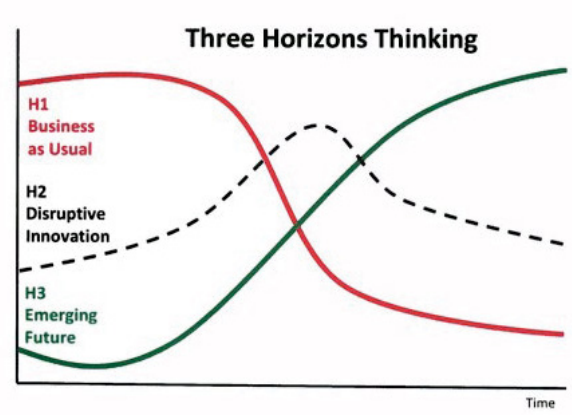

Figure 1-1 Three Horizons Framework (Sharpe et al. 2016)

In this study consider that H1 represents business as usual, based upon fossil fuel economies. H2 represents the disruptive blockchain technology applied to carbon trading. H3 represents a desired future, a shift away from fossil fuel use (Sharpe et al. 2016). The H3 emergent future here is seen as a carbon negative system with incentives for regenerative climate initiatives. This is not to say blockchain is the H3 future, but it is poised to be a tool that disrupts the flow of anthropogenic carbon emissions and allows for the financing of sustainable initiatives from carbon credits in VCMs, giving rise to H3.

Some recent studies find that to avoid adverse climate change, carbon removal is critical. For instance, The Sixth Assessment Report of the Intergovernmental Panel on Climate Change reports that avoiding the worst of climate change relies on preventing as many GHG emissions as possible as well as removing CO2 already in the atmosphere. The report quotes that "the deployment of CO2 removal to counterbalance hard-to-abate residual emissions is unavoidable if net zero CO2 or GHG emissions are to be achieved. The scale and timing of deployment will depend on the trajectories of gross emission reductions in different sectors. Upscaling the deployment of CO2 removal depends on developing effective approaches to address feasibility and sustainability constraints especially at large scales," (Shukla et al. 2022, SMP-47).

Effective adaptation options listed in this report include carbon sequestration and storage around nature-based solutions (NbS) which delivers climate change adaptation and/or mitigation benefits. NbS as defined in the report by The World Conservation Union defines it as "actions to protect, sustainably manage, and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits," (Cohen-Shacham et al., 2016). Forest restoration, ecosystems such as savannas, grasslands, peatlands, wetlands, and mangroves have considerable value in acting as carbon sinks as well as providing other ecosystem services, as well as regenerative agroecological practices are all NbS which contribute to both climate mitigation and adaptation and are recommended as tactics for carbon sequestration (Pörtner et al. 2022, 1-55).

Furthermore, the Science Based Target Initiative (SBTi), responding to the urgency of decarbonization, designed a Corporate Net-Zero Standard to provide a standardized and robust approach for corporations to set net-zero targets which are aligned with climate science. In collaboration with CDP, United Nations Global Compact, World Resources Institute, and World Wildlife Fund, SBTi published the Standard in October 2021 which defines corporate net-zero as follows:

- Reducing emissions to zero or to a residual level that is consistent with reaching net-zero emissions at the global or sector level in eligible 1.5°C-aligned pathways.
- Neutralizing any residual emissions at the net-zero target year and any GHG emissions released into the atmosphere thereafter (Science Based Targets Initiative 2022).

At the heart of SBTi Net Zero Standard is a principle – the mitigation hierarchy – that seeks companies to "set science-based targets, both near- and long-term, to address value chain emissions and implement strategies to achieve these targets as a first order priority ahead of actions or investments to mitigate emissions outside their value chains." (Science Based Targets Initiative 2022). The further work beyond value chain mitigation, it posits, include "purchasing high quality, jurisdictional REDD+ carbon credits that support countries in raising the ambition on, and in the long-term, achieving their nationally determined contributions… [investment] in nascent GHG removal technologies (e.g., direct air capture (DAC) and storage) so that the technology is available to neutralize residual emissions at the long-term science-based target date." (Science Based Targets Initiative 2022).

1.6 Research Question

The main research question for this thesis is:

"*What are possible roles of blockchain technology in carbon trading and voluntary carbon markets through a sustainability lens*?"

The secondary research questions are:

1. Could carbon offsetting in the voluntary carbon credit markets via blockchain based technology potentially increase the supply of carbon credit projects?
2. Does the use of blockchain technology strengthen voluntary carbon buyers' commitment to net-zero?
3. Does the use of blockchain technology contribute to the production of high-quality carbon credits?

4. Does the use of blockchain technology promote fairness in carbon trading?

2 Derivation of Conceptual Framework

Situating blockchain technology in the voluntary carbon markets requires a sustainability lens from a systems thinking perspective, considering the complexity of the socio-ecological system. The carbon trade is a transitioning phenomenon as explained using the Three Horizons framework and the objective of the transition is to contribute to the climate change mitigation goal. In deriving our conceptual framework, we distilled thoughts from academia and industry. Our review of the recommendations of The Oxford Offsetting Principles and the Taskforce on Scaling Voluntary Carbon Markets (TSVCM) informed the establishment of our conceptual framework to answer our main research question. To give context – carbon trading started in 1997 after 180 countries signed the Kyoto Protocol and the objective was to limit the emission of GHGs (UNFCCC 2022a). Because of the challenges faced by the voluntary carbon market, there are concerns that carbon trading may not be effective. Some of the challenges that affects carbon trading includes credibility of the accounting method used and feasibility of business models, especially the concern that supply may not be sufficient to meet demand (Kreibich and Hermwille 2021, 940). TSVCM and The Oxford Offsetting Principles are guidelines that attempts to define behaviors that society should follow to fix these problems and improve their systems. The Sustainability Principles (8SPs) of the Framework for Strategic Sustainable Development (FSSD) are boundary conditions within which parties in a socio-ecological system can achieve sustainability. Given the complementary nature of these guidelines, and the application of the 8SPs to interrelated systems, we employed each in framing our sustainability lens for probing blockchain and carbon credits trading in the voluntary carbon market, in cognizance of corporate climate action commitments/targets like the Net-Zero Standard.

2.1 Sustainability Principles (the SPs)

To address the sustainability challenge, it is important to have a science-based definition of what sustainability is. Sustainability has been defined perhaps most famously by the Brundtland Commission: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to mee their own needs.” (Brundtland, 1987). While this definition describes what sustainability is, it does not give clear access points for actions to take to achieve sustainability or recognize the systemic issues facing the socio-ecological system which lead to an unsustainable society. The FSSD gives a definition of sustainability through the 8SPs, which are science-based sustainability principles elaborated in the multidisciplinary field of systems thinking (Broman and Robèrt 2017, 23). This definition’s strength is that it is clear enough to identify whether sustainability has been achieved by focusing on upstream causes of unsustainability. There are eight principles, the first three address ecological sustainability, and the last five address social sustainability. The SPs from Broman and Robèrt 2017 are as follows:

In a sustainable society, nature is not subject to systematically increasing:

1. concentrations of substances extracted from the Earth’s crust;
2. concentrations of substances produced by society;
3. degradation by physical means;

and, in that society, people are not subject to structural obstacles to:

4. health;
5. influence;

6. competence;
7. impartiality;
8. meaning-making.

The use of the SPs for the sustainability lens of this thesis is to enable a systems thinking perspective which is needed for considering the sustainability of a system. As seen in Figure 2-1, this thesis views the blockchain system as nested within the VCM, the larger carbon trading market, and ultimately the socio-ecological system. The SPs are boundary conditions applicable to all interrelated systems in the figure. By taking this approach it is possible to form a holistic view of the systems interrelation to identify what structural obstacles the blockchain application for carbon credits inherits from the systems it perpetuates, aligns with, or violates as identified by the SPs. This approach is also a more systematic way of evaluating any pitfalls of using blockchain technology for the sustainability goals, rather than the siloed criticisms about the technology that has fuelled debates in literature.

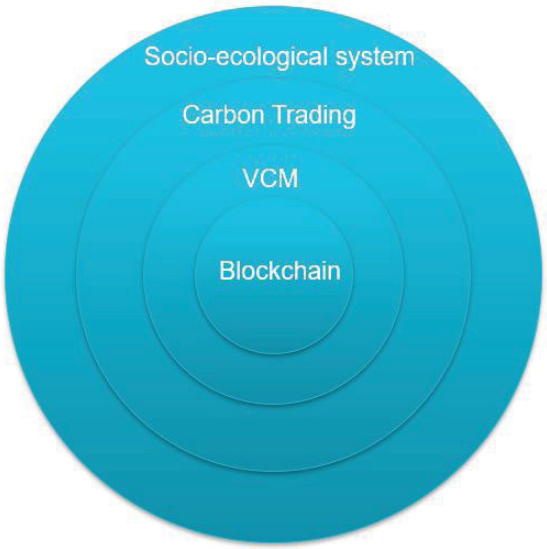

Figure 2-1 Nested Systems

2.2 The Oxford Offsetting Principles

There are four key elements to credible net-zero aligned offsetting for parties seeking to offset their carbon emissions, according to the multidisciplinary team from the University of Oxford (Allen et al. 2020):

1. Prioritize reducing your own emissions first, ensure the environmental integrity of any offsets used, and disclose how offsets are used.
2. Shift offsetting towards carbon removal, where offsets directly remove carbon from the atmosphere.
3. Shift offsetting towards long-lived storage, which removes carbon from the atmosphere permanently or almost permanently.
4. Support for the development of a market for net-zero aligned offsets.

2.3 The Taskforce on Scaling Voluntary Carbon Markets (TSVCM)

The TSVCM establishes six sections for accelerating carbon trading and reaching net-zero (Taskforce on Scaling Voluntary Carbon Markets 2021):

1. Core carbon principles and attribute taxonomy;
2. Core carbon reference contracts;
3. Infrastructure: trade, post-trade, financing, and data;
4. Consensus on legitimacy of offsetting;
5. Market integrity assurance;
6. Demand signal.

2.4 Conceptual Framework: A Sustainability Lens

Both The Oxford Offsetting Principles and the TSVCM identify behaviors that socio-ecological systems should follow to make carbon trading effective for reaching net-zero. Our conceptual framework contains a niche set of criteria that is derived from these frameworks that is relevant for investigating the application of blockchain in voluntary carbon markets in the organizations we collaborated with in our research. Although both frameworks covered environmental, economic, and governance aspects of sustainability, they leave some gaps for understanding the social and technological considerations helpful for answering our primary research question from a systems perspective. For social considerations, we adopted some aspects of the scientific foundations of the social SPs e.g., trust and human need (Broman and Robèrt 2017, 23), to identify sustainability areas we adjured important for our research. These aspects were adjured important because they target popular narrative of the use of blockchain technology in literature, e.g., decentralized governance system, transparency, and accountability (Leonhard 2017, 28; Thedéen and Risinger 2021; Zhao and Chan 2020, 1). Because of the inherent nature of technology to disrupt systems, we also put blockchain technology in the context of whether it is flexible for forthcoming steps which, taken together, are likely to support society's transition towards sustainability (Robèrt et al. 2015, 13).

We fleshed out the nuances these aspects hold into five themes, which we define as our sustainability lens, below:

1. Social
    a. *Human need*
    b. *Inspiration for society*.
    c. *Societal license to operate*.

2. Environmental
    a. *Environmental integrity*
        i. Support the restoration and protection of ecosystems.
        ii. Support the prevention of the re-release of stored carbon.

3. Economic
    a. *Market maturation*
        i. Catalyze structured finance.
        ii. Improved liquidity from standardized contracts.
        iii. Demand signaling.
        iv. Scale up high-integrity supply.
    b. *Return on Investment*.

4. Governance
    a. *Systems and structures*: Global anti-money-laundering (AML)/know-your-customer (KYC) guidelines, accounting frameworks.
    b. *Carbon credit integrity*
        i. Offset eligibility guidelines and principles for offset standards, suppliers, and validation and verification bodies.
        ii. *Disclosure*: (e.g., of current emissions, accounting practices, targets to reach net-zero, and the type of offsets employed).
        iii. *Transparency*.

5. Technology and Innovation
    a. *Advanced data infrastructure*
    b. *Efficient and accelerated carbon verification and retirement.*
    c. *Ease of carbon credit trading.*
    d. *Technology platform is flexible* for applications that can help reach net-zero.

3 Methods

3.1 Research Design

The design for the study was informed by the primary question: "*What are possible roles of blockchain technology in the voluntary carbon market through a sustainability lens?*"

The aim of the study was to be able to state the specific contribution, negative or positive, of the application of blockchain technology to the voluntary carbon market. The objectives included understanding the roles of the use of blockchain technology in new carbon project development, contribution towards net-zero, the quality of carbon credits developed in these new projects, and fairness of carbon trading.

To achieve the above aim and objectives requires inductive reasoning and the sample size for our research is small (seven organizations); hence, the strategy used in our research was qualitative research strategy, which generates and analyses empirical materials and improves understanding that is novel to the scholarly community (Aspers and Corte 2019), and the research method used was interviews. We used an explorative method in designing our interview questions to understand this new niche market and subsequently advancing knowledge through building new hypotheses. We summarize the research design in Table 3-1:

	Research Steps	**Data Collection Method**	**Data Analysis Method**
1	Development of Thesis Proposal	Online exploration of scientific and non-scientific articles and publications on blockchain, VCM, and socio-ecological systems.	Intersystem analysis by providing overall context and rationale for the research topic to derive research questions.
2	Development of Conceptual Framework	Distillation of topic-relevant guidelines from industry and academia.	Adopted aspects of the guidelines that are applicable to the analyzed intersystem.
3	Qualitative Research	Semi-structured interviews and surveys collected from collaborating organizations for the research study.	Inductive and deductive analysis of recurring patterns (codes) in categorizing data aligned with the conceptual framework, allowing for new themes to emerge.
4	Evaluation of Research Results	Summary of data from qualitative research above.	Result interpretation from a sustainability lens.

Table 3-1 Research Design Summary

3.1.1 Preliminary Research

The criteria for including an organization in our study, informed by literature review with a systems perspective during the thesis proposal development phase of the research design, are: the organization is a player in the voluntary carbon market, and the organization uses blockchain technology as a market infrastructure in the voluntary carbon market. Noteworthy is that professionals in the blockchain- voluntary carbon market- industry suggested organizations for the thesis team to consider for the purpose of the research study. Below is the list of organizations, with their web links, that the thesis team collaborated with for this research study:

1. Creol (https://www.creol.io/)
2. Flowcarbon (https://www.flowcarbon.com/)
3. KlimaDAO (https://www.klimadao.finance/)
4. Nori (https://nori.com/token)
5. ONCRA from Climate Cleanup (https://climatecleanup.org/accounting/)
6. Offsetra (https://offsetra.com/)
7. Toucan (https://toucan.earth/)

3.1.2 Data Collection

Semi-structured interviews were conducted with the seven collaborating organizations. Interviews comprised 15 questions which were derived from the Conceptual Framework in four iterative steps: first, individuals on the thesis team contributed to a long list of questions that were relevant to answering the research questions; second, ranking of the questions using two different weighting techniques on a table was performed to ensure consistency of shortlisted questions, third, the shortlisted questions were subjected to critique of the thesis research team, finally; a practice run of the questionnaire with select master's program course classmates was completed to measure the validity of the questions. The final questions were shared with the organizations before their respective interview dates. The organizations were implored to invite colleagues working in any, or at the intersect, of these (or related) functions: Product Management, Enterprise Risk Management, ESG/Sustainability, Finance, Programming, Partnerships/Business Development. The interviews were conducted via online video conferencing platform. Each interview session lasted approximately 90 minutes. Upon a contingent revision of the Conceptual Framework post-communication of the interview dates, coupled with a preliminary assessment of the interview responses, a 15 question written survey was designed and shared with the organizations after completion of interviews. The full list of interview and survey questions can be found in Appendix A1 and A2.

3.1.3 Data Analysis

After conducting interviews, the recordings were uploaded to the digital online transcribing tool, otter.io. The audio recordings were automatically transcribed into text by the tool's artificial intelligence. The texts were manually checked for grammar, spelling, punctuation, and flow. The checked transcripts were then exported into an editable format to begin coding.

The coding structure created for analyzing the results was a combination of inductive and deductive analysis. The first step to code the data was to identify the major themes that came up throughout the interviews. These were further broken down to create more specific codes within the themes. From this process, 11 themes and 45 codes were identified. While coding

the interview transcripts, each interview transcript was reviewed by two authors in succession. Coding was done digitally in a word processor by highlighting relevant pieces of data within the transcript and adding comments containing the assigned codes. Finally, the data was summarized in a table to identify patterns more easily from across the seven interviews with code and interview question specific filters. Insights from the interviews were combined with the information gathered from the written survey and are presented in Chapter 4 Results. The codes generated are provided in Appendix A3.

3.2 Ethical Considerations

Establishing ethical transparency while working with multiple organizations required us to establish clarity around our intent and content of the research conducted. Pre-interviews, we set up a short introduction session with each organization to establish a mutual relationship and familiarize the organization with the objectives of the study. Consent forms were sent out to each organization to be signed before the interviews commenced. The forms showed the rights of each respondent and the conditions for consent. In this report, the transcripts of interviews with the organizations are not given in full context of the individual organizations and direct quotes are used anonymously. According to the institutional standards of Blekinge Institute of Technology, data was stored temporarily on a closed drive throughout the duration of the study.

3.3 Limitations of Study

The scope of our study is defined by our conceptual framework which explores aspects of social, environmental, economic, governance, and technology aspects of the studied organizations. Given that the niche market of blockchain for carbon trading is still young and growing, we only included as many organizations as were available for contact. On the premise of the growing niche market coupled with the fast-changing, disruptive nature of technology, the market dynamics at the beginning of our study may not be the same with that at the time of completing this report.

Another limitation to the study was time constraint. Albeit we purported to include case studies of each organization interviewed in our research method, the available time to complete this thesis towards our advised final thesis submission date necessitated the cancelation of this plan. This time constraint consequently affected the robustness of our data. We acknowledge that more insights could have emerged if more time was available to study the organizations and their open resources in details. The newness of the application of blockchain with the carbon market also means there is no longitudinal data to test the validity of many claims gathered in the interviews/survey.

Furthermore, the criteria for including an organization in our study did not take into cognizance their geographical locations; the participating organizations turned out to be based in Europe and North America only, albeit some with projects that extended beyond these regions. Hence, our findings are not representative of the global blockchain- voluntary carbon market- system.

Lastly, even though respondents spoke on behalf of their organization, it is important to note that some responses may not comprehensively express the stand of the organization, the blockchain-carbon credit system, or the broader socio-ecological system, due to the individuals' bias of opinion.

4 Results

This chapter is a summation of the data obtained from the interview process and the written survey, along with supporting data obtained online. The sections in this chapter are organized reflecting the themes of our framework. Each sub header is broken out according to the results from our coding process and listed with the corresponding code. The results from the additional survey sent out are also included in the Infrastructure and Technology as well as the Social section below. The content summarized within has been reported with a focus on the data necessary to answer the primary and secondary research questions through the sustainability lens of the SPs and supporting framework outlined in Chapter 2. The participants names and associated organizations have been anonymized and replaced with 'Organization X' as a pseudonym, numbered 1-7. The full of interview questions, survey questions, and table of codes with explanations are provided in Appendix A1, A2 and A3.

4.1 Social

The topic of how the application of blockchain with carbon credits intersects with social aspects of the socio-ecological system is identified and elaborated below.

4.1.1 Benefits (S1)

All organizations interviewed pointed at the project developers as the beneficiaries enjoying the most value of the technology. They cited faster access, transparency, additional income for regenerative practices, self-service, and meaning making in community as benefits they derive. Organization 3 also mentioned the local communities and the projects as beneficiaries. They mentioned projects that have a social impact in communities as their future investment considerations. Organization 5 listed climate entrepreneurs who are working with climate solutions with nature-based techniques as primary beneficiaries, small and medium enterprises who are looking for ways to communicate that their short- and long-term climate goals as secondary beneficiaries, and the natural environment as another stakeholder that benefits from their technology. For Organization 6, given that their biggest product is around building control systems, the main beneficiaries of the value of the technology are people who stand to gain energy efficiency.

4.1.2 Benefits – Supply Specific (S1a)

Farmers

Organization 2 responded that the suppliers are their priority in terms of return on investment, and mentioned creating consistent demand for the suppliers of carbon credits. Organization 4 responded that there's an incentive for some suppliers because it costs marginally less for them to earn money for practices that they've recently implemented. Comparing the cost of verifying carbon credits on-chain with that of traditional, they asserted that the elimination of the need for on-site visits drove the price down almost tenfold. Organization 4 mentioned that the technology they employ incentivizes these suppliers to sell their carbon credits immediately so long as they comply with the organizations standards.

4.1.3 Benefits – Buyer specific (S1b)

User Experience, Open Access, Communications

Some benefits hinged on user experience. Organization 2 shared that they are bringing new audiences to the carbon market, citing the difficulty in the way end users get hold of carbon credits as a point of value addition especially with brokerage of credits. They also reported open access to purchase carbon credit and provision of a mix of carbon credits from different projects for small businesses who are without strong finance but are willing to help fight climate change. Organization 1 likened this benefit to e-commerce, where everyone wants to trade quickly and easily online. Organization 4 mentioned communications as a value for buyers, whereby they (buyers) can showcase their efforts via information materials and certificates. Organization 5 described their client's investment as a communication investment, as their return on investment—which they referred instead to as Return on Planetary Investment—is much more towards their communication goals.

4.1.4 Trust (A3)

Organization 7 posited that blockchain enables a more trustworthy form of financing for projects in some countries that don't have mature financial systems, explaining that bringing in new pockets of capital from other markets in a way that people trust and feel comfortable doing is a way to build momentum in those countries. Organization 2 opines that the disintermediation of the carbon market by blockchain means that buyers can have a lot more confidence that what they're buying is fair. Organization 4 thinks transparency is necessary to have trust in the accounting systems, stating that blockchain has a strong case for providing that ultimate transparency, laying claim to the immutable nature of the system.

Shared Values, Legitimacy of Carbon Credits

Organization 5 credits their success to the motivation of the people they have worked with, citing them as having a pro-social mentality and being intrinsically motivated from an environmental, social justice, or an ego perspective. For Organization 1, having shared values and a market need of their infrastructure is a strong consideration for aligning with any investor. In trying to bring legacy consumers on chain, Organization 2 stated there is a big question of trust on whether the on-chain credits are legit. Organization 1 stated that they tokenize only credits from established international standards, citing Verra and Gold Standard as examples. To give buyers insurance on the carbon credits purchased, Organization 5 stated they keep excess of sequestered carbon (30%) in a carbon vault for all the carbon sequestered for sale.

4.1.5 Education (S2)

Self Education

Organization 6 asserted that people are very interested in having data of their carbon emission footprints and are looking for ways to reduce their emissions. Organization 6 also attributed the growing community of people in Web3 to the cool nature of the technology that pushes people to make sense of it, echoing Organization 7's response that people are self-educating quickly. Organization 4 stated that throughout the process of purchasing credits, their clients are on a learning curve, as they seek to make additional contributions. Yet, Organization 6, Organization

7, and Organization 2 posited that the biggest barrier to adoption of the tech is education/understanding of blockchain technology.

Domains of Knowledge Gap

For Organization 6, it is education on three domains–the blockchain market, carbon project, and carbon market, stating that the opportunity to sell the technology exists in a the subset of people who understand all three domains. They also mentioned how criticisms against the blockchain has destroyed the reputation of the technology because of ignorance. For Organization 2, it is both education on blockchain technology and the legacy carbon credit market, revealing an education gap in the amount and type of carbon credits needed for purchase by buyers already sold on the benefits of sourcing carbon credits on-chain. Organization 1 thinks blockchain ecosystem has done well in terms of education on best practice for offsetting, especially in companies that have an ESG department, but they mentioned being able to interact with blockchain as a user as a barrier to the adoption of the technology.

Public Information for Education

To enlighten the public on some specific benefits of the technology, many of the organizations studied have some information or communication materials open for public education. Examples of information presently or intended to be available for public consumption in the future include carbon verification methodology, criteria for choosing projects, definition of high-quality project and the methods used internally and externally to assess that. Organization 5 is taking a more direct approach – they are giving farmers a self-service toolkit that helps aid verification of carbon faster, explaining that people want to make an action and have some agency. Organization 3 mentioned it has already conducted analyses of its clients' carbon emissions disclosures for public consumption. Organization 1 believes an educational campaign before smarter solutions is required first.

Others

Organization 2 mentioned they are happy to advise where they can on carbon strategy. They also intend to use the huge amount of data generated from the market activities on chain to build dashboards and metrices to help standard bodies monitor the carbon market in a way that is not currently possible. Organization 5 are hopeful of having an emblematic or iconic project for communication purposes against the criticisms on the environmental friendliness of blockchain technology. Organization 4 believes that holding informative, fruitful conversations with buyers has downstream effects in terms of how they mitigate emissions.

4.1.6 Rebound Effect (S3)

Awareness of Carbon Footprint

On the rebound effect of carbon offsetting (i.e., benefits from carbon offsetting encouraging behavioral change towards more energy use that "take back" from these benefits), Organization 6 stated that people just feel better about what they do. Organization 7 opined that corporates looking for offsets have made commitments to carbon neutral neutrality so are simply looking for a solution more than they're looking for an excuse to offset more. This is corroborated in Organization 2 response, who stated that people who have purchased carbon credits in a retail context are already doing sustainable things, stating that carbon marginally impacts their

decision making. Organization 5 opined that at the point of purchasing carbon voluntary carbon offsets, a buyer is very conscious of her carbon footprint and actions.

Economics of Rebound Effect

Organization 2 opined that the benefits of utilizing blockchain technology has more impact on any decision making compared with the carbon emissions associated with them. Organization 7 also thinks that at some point, conditional upon market liquidity, it will become more cost efficient to just not emit than to buy carbon credits. But they also expect that there will be more interest in carbon credits due to high penetration of blockchain in low-income countries. Organization 2 acknowledges the risk of the rebound effect but thinks it is not enough reason to do nothing. They concluded that any offsets from non-fungible tokens are probably an additional revenue that's being created because of economic activities on the blockchain, which give benefits to the carbon market.

Organization 7 alluded that the rebound effect can be the case for corporates who aren't committed to following a standard such as SBTi's Net-Zero Standard. Organization 2 argued that for the rebound effect, particularly in a small and medium enterprise, there are some economic factors in play more than the carbon issue. Organization 1's response was similar, stating that one needs to look at several aspects of what influences the behavior of corporate buyers, opining that purchasing credits is more of a symptom of an underlying behavior that was introduced to them. Organization 5 submitted that investment often goes into projects that are not in themselves carbon neutral but the process flow of the scalable project will be carbon neutral, with each project having a research and development part that tracks energy flows to monitor and validate carbon neutrality. They alluded to not selling carbon credits to some organizations, for instance, petroleum companies, saying it's just not helping. Organization 5 concluded that it's the whole process of becoming aware of process flows, energy flows, impact of financial decisions, and externalities after conducting a greenhouse gas protocol-based assessment that helps in purchasing carbon credits ion a meaningful way.

Organization 4 thinks that education that comes throughout the process of purchasing carbon credits influences mitigating emissions at the source and rearranging operations to be more friendly can help build a restorative future. Organization 1 submitted that blockchain technology helps corporates become more aware on a regular basis of the need for offset, citing high rise in the price of carbon offset last year influenced by more maturation of purchasing behavior.

4.1.7 Societal license (S4)

Organization 5 stated that blockchain resides within systems that is based on a very tenuous trust. They opined that the distrust around blockchain technology is a communication war and as long as the anti-sentiments isn't strong enough to really destabilize the technology, then blockchain will see constant growth in the systems. Organization 2 opined that it will take time for the fully on-chain protocols to establish the same level of credibility as the legacy carbon market. Organization 4 mentioned they are trying to democratize the technology to include people, e.g., farmers, who may have been traditionally overlooked but are more excited about the technology than even tech folks. Organization 5 found that in the voluntary carbon market, people are not too concerned about the loss of carbon, as they are solution seekers interested in understanding how such risks are being managed.

4.1.8 Partnership (S5)

Organization 5 stated that they only work with projects directly involving government stakeholders, highlighting benefits like ecosystem services putting a value on that being traded. They also highlighted co-branding benefits and management of blockchain criticisms in external relations as a benefit of partnerships. Because of the cost of developing carbon credits with co-benefits, Organization 5 expressed their need to work with partners that can help them work through the market side of things, arguing that provincial and local government fit the partner role well because they understand the core benefits that the carbon market doesn't. Primary for Organization 3 in their consulting activity is that it is related to companies that interact with blockchain technology. Organization 2 mentioned their collaboration with Verra to grow their treasury as well as with their partner organization that bridge carbon credits on chain. They also mentioned a partnership with an organization on Internet of Things to help with verification of projects on chain.

Opportunities for Partnership Development

Organization 3 advised that in projects protecting forests, there is a need to work with local communities to make that effective. Also, they identified that partnerships are not fully established between the standards bodies and bridging entities to make companies feel more comfortable about sourcing on chain - which is a challenge in building up demand on chain. Organization 1 acknowledged that they're not experts in measuring their own carbon footprints, so they rely on experts to do that for them. Organization 4 mentioned they seek to find partners that can help their clients with GHG emission accounting, opining that there is a conflict of interest in telling people how much carbon credits to buy and still selling them the same thing to buy. Organization 2 expressed willingness to link organizations seeking a carbon or environmental strategy to consultancies that could provide the carbon accounting process for them. Organization 5 suggested that the methodology for working with clients can be peer-reviewed and scientifically accepted to give metrics that they can build on. On future expectations, they commented that they would like to see themselves working with an external partner on blockchain networks so they can dedicate themselves to market integration, verification, and certification.

4.1.9 Survey Results

On gender balance within their design team, one out of the seven organizations surveyed did not return the survey even after sending two reminder emails. Two out of the six organizations who returned our survey responded that their design team is evenly balanced. One organization responded that they have a fairly equal gender split. One organization responded that they have only one design person who is female, citing the small size of their organization, but also mentioned further that there's an equal split between women and men among the employees and around half of the leadership team identify as females. One organization responded that the ratio of women to men in their creative team is 1:5, the team being headed by a female. One organization responded as not being gender balanced at all, also citing their small size.

4.2 Environmental

Throughout the interviews information was gathered on what environmental aspects within the intersection of blockchain and carbon credits are. The subtopics identified through coding are elaborated on in the sections below.

4.2.1 Types of Carbon Credits (C1)

During the interviews, types of carbon credits mentioned varied from talking about the kind the organization uses, to the future of the sector possibly being able to trade more abstract types of credits, to advanced projects using Internet of Things (IoT) and other advanced technologies to bring credits directly on chain.

Types of carbon credits supplied by the organizations included regenerative agricultural credits, REDD+ (Reducing Emissions from Deforestation and forest Degradation, and the plus stands for the role of conservation) credits, renewable energy carbon credits which displace fossil fuel energy sources, nature-based solutions such as mangrove plantations, and more.

Organization 7 predicts the future of trading markets will innovate beyond carbon, into things such as biodiversity, and clean water, built on top of the carbon market infrastructure. In relation to types of credits, some credits are seen as more valuable to different organizations or buyers, such as a credit coming from a renewable energy project ensuring more permanence than one from a forestry project. This is discussed in the section 4.2.2 Quality Credits (C3) in relation to quality credits and permanence.

Three organizations mentioned involvement or plans to include a project based around supplying advanced cookstoves to replace inefficient ones in rural households which target carbon credit creation at the source. Inefficient indoor cookstoves create emissions and respiratory health problems of those who use them, disproportionately affecting women. The advanced cookstoves monitor the fuels used using Internet of Thinks (IoT) devices which record the usage data from those cookstoves on chain as a verifiable way to show that the action associated with the methodology is being carried out in a verifiable manner. The carbon emissions avoided are then sold as a carbon credit which can help finance the cookstoves for the receiver. This reduces the need for a physical auditor and creates immutable carbon credit data at the source.

4.2.2 Quality Credits (C3)

The topic of quality credits was an issue emphatically replied to during the interview. The range of answers varied by organization as to what a ‘quality credit’ entailed with nuanced features of what it meant to each. A few themes followed throughout the interviews, referring to additionality, permanence, and co-benefits as qualities which created more value for a carbon credit. These are part of the International Carbon Reduction and Offset Alliance (ICROA) accreditation principles which dictate that carbon credits must be real, measurable, permanent, additional, independently verified, and unique (ICROA 2021). A table outlining the different responses from each organization and how the interviewees interpreted what a ‘quality credit’ is included in Appendix A5.

4.2.3 Permanence (C3d)

The subtopic of permanence was highlighted during the interview questions as an essential aspect of the thesis framework. The question was asked "What measures, if any, are taken for accountability of ensuring the carbon stays sequestered?" Responses generated ranged from the liability being left to the verification bodies which approve the carbon credits the organizations interviewed bring on-chain, to challenging the legacy market principles, which typically ensures 100 years of permanence, saying that a 10-year metric makes more sense given the urgency of the sustainability challenge needing solutions as fast as possible.

The five organizations interviewed who rely on agencies such as Verra and/or Gold Standard all allow the verification bodies to have domain over ensuring permanence. These organizations note the verification bodies are the ones most qualified to issue credits, and that they are relied on for a level of assurance. Organization 7 notes that Verra's current policies for monitoring permanence is improving with some pressure from rating agencies. The two organizations which do not use Verra or Gold Standard keep a buffer of carbon credits in order to have an insurance on what permanence may be lost by natural disaster or breach of contract to ensure buyer confidence.

One organization interviewed follows the ICROA standards, but they diverge from the legacy market principles with respect to permanence and additionality. This organization guarantees permanence for 10 years instead of the international standard of 100 years. They uses the 10-year metric because they believe it makes it more accessible for suppliers to endorse, and the ideology also relates to the urgency of climate change that it is better to have solutions as soon as possible.

4.2.4 Benefits (E1)

Carbon credit projects supported through the organizations interviewed are believed by interviewees to support ecosystem health through enabling multiple methodologies of carbon removal projects. This section overlaps greatly with 4.2.2 Quality Credits (C3) section, where organizations discuss co-benefits and ecosystem services associated with creating carbon credit projects.

4.2.5 Emissions for Buyers (E2a)

Three separate organizations mention that corporate spaces are now following the Science Based Targets Initiative regarding setting emissions targets and the hierarchy of actions for reducing carbon that the initiative sets, which is that emissions are to be reduced as far as possible before purchasing offsets. Another point brought up for reducing emissions is cost to clients. Four organizations bring up the argument that at some point, it becomes more cost efficient to just not emit instead of buying offsets. Carbon reductions for a business are proportional to some reduction in cost. This is implied by the organizations interviewed to be a stronger reason for VCM buyers to reduce emissions beyond environmental concern or SBTi.

Four organizations interviewed talk about how buyers should be calculating offset targets from a third party and that the first step of any kind of carbon strategy or environmental strategy is the calculation. Within these organizations there is a theme that using a third party is better since it results in a non-biased view of buyers' emissions and a quote for how much you should

buy from offset marketplaces, and an avoidance of a conflict of interest. Organization 4 believes that there is an opportunity for these calculators to be better.

4.2.6 Emissions for Blockchain (E2b)

Across all the organizations interviewed there is an emphasis on the blockchain for carbon credits industry switch from a PoW blockchain system to a PoS for environmental reasons. It is cited from all organizations interviewed that switching to a PoS system is magnitudes lower than PoW in emissions and energy efficiency and requires less specialized hardware to be manufactured.

Polygon, a blockchain which is popular amongst organizations which trade carbon credits, is a decentralized Ethereum scaling platform which uses PoS validation to operates in an energy efficient way (KlimaDAO 2022). An analysis done by Offsetra applied their PoS and PoW network emissions methodologies to compute Polygon network emissions. Polygon operates as a semi-independent sidechain that runs in parallel to Ethereum Mainnet, where periodic check ins, such as bridging and checkpointing, results in a situation where both PoS emissions and PoW emissions must be accounted for. Total emissions for Polygon since its inception equate to 90,654 tonnes CO2e (carbon dioxide equivalents), with Ethereum Mainnet activities having generated the majority of emissions calculated at 90,000 tonnes CO2e (KlimaDAO 2022). As the Ethereum Mainnet is planning to switch to a completely PoS system in Q3/4 2022 (Ethereum 2022), emissions from the Polygon network are expected to decline. Organization 2 notes that there is not a standardized approach for emissions calculations within crypto carbon accounting.

4.2.7 Energy (E3)

Organization 1, Organization 2, and Organization 4 touch on the fact that calculating energy for both buyers as well as blockchain industries is difficult due to the ambiguous nature of electricity, and that those who calculate their footprints don't know what electricity is being used, whether it's from coal or wind. Skepticism around the amount of energy that blockchain platforms use is noted as a barrier to adoption by Organization 7. Organization 2 stresses that a priority is decarbonization of the power system and goes on to talk about how carbon credits that enable renewable energy as a solution should be considered legitimate. Organization 7 references renewable energy projects that weren't financially viable, until carbon crediting system was able to get those projects off the ground.

4.2.8 Urgency of Problem (E4)

For this section, scaling up carbon removal, having multiple solutions, and the fact that after society stops producing carbon there will still be a need for removal are the key discussion points.

The urgency of the problem was touched upon in interviews and continuously came back to the idea of scaling the problem. Five of the organizations interviewed all highlighted the idea that the platform they offer helps to increase the accessibility of which they are purchased. This increase in the scale of action required is believed by the above organizations to be necessary to achieve a meaningful impact on the climate issue. All the organizations interviewed allude to the production of carbon continuing to be endemic, and that carbon removal will continue for the foreseeable future.

Organization 2 notes that if it is believed that the carbon market is one of the tools in the climate change toolbox, there is currently still a gap in volume of carbon credits available, but an innovation such as making carbon credits available on blockchain empowers the carbon market to enable urgent action. Organization 4 reflects on credits which may have less permanence compared to other methods but are more accessible for scale, noting that if climate action needs to be addressed in a couple decades before there's irreversible damage done to the planet, throughput matters more than permanence compared to the projects sequestering carbon for 100 or 1000 years.

Organization 6 notes that as these mechanisms are created, it allows everyone to work together, and the speed of the transition that blockchain has been allowing in the carbon credit market has been creating a community which is accelerating action to address the climate crisis. They also noted that "it's not going to be five solutions that take away 20% of the emissions, that's going to be hundreds of solutions that take away small pieces here and there. So, for every little solution that you add up, and you come up with, you know, that's a good thing, it's a net positive."

Organization 2 notes that a clear pressure in the market is seen to focus on nature-based solutions and drawdown rather than just mitigation. Organization 4 also notes that even after decarbonization is achieved there will still be a deficit that needs to be removed. Organization 6 opined that to achieve carbon neutrality by 2030, more works needs to be put in than just the minimum standards. Organization 4 and Organization 5 relate the best parts of using the blockchain (trust, accessibility, transparency) within the system directly to the urgency of the problem, noting that the more people that have faith in the system, the more people will participate, which leads to scaling. They also have faith that the system will continue to become more accessible, continuing the increase in scale.

4.3 Economic

Economic aspects mentioned of the interviews are summarized in the following sections.

4.3.1 Scalability (A5)

Organization 7 also opined that more access will bring more stakeholders to the voluntary carbon market. Organization 2 argued that bringing new audiences to the carbon market implicitly raises the work profile of their partner carbon registry. They also highlighted the reduced income to project developers because of broker-dominated markets. Organization 2 suggested an opportunity for blockchain technology to create an end-to-end supply chain for the carbon markets that is a hybrid approach of blockchain technology and the carbon verification and credit issuance infrastructure of legacy carbon registries. Organization 5 stated that they work with project developers to create what their potential buyers want in terms of certification and authorization.

Organization 2 expressed they are more concerned with both the volume and the quality of carbon credits, stating that the same volume with higher quality will not achieve the scale of impact required for addressing climate change through a market-driven approach. They estimated the scale of action required for the voluntary carbon market to achieve a meaningful impact on the climate issue as a 10- to 100-time increase in the annual volume of credits being currently produced and consumed. This, they explained, informed their decision of starting with

the two major carbon registries Verra and Gold Standard – they have the volume. Citing the millions of tonnes of carbon in Organization 2's treasury, Organization 6 opined that blockchain enables the creation of financial mechanisms that allow a small group of people working together to create something big.

Organization 3 posits that the delivery of capital to the project developers increases the market throughput and has a bearing on scaling up the development of current projects. Organization 5 submitted that working with their project developers becomes more rigorous as they scale their sales, so they also scale their due diligence process because of the increased chance of a carbon market failure as the provider and buyer circle gets wider. Organization 1 stated that the carbon market needs some piece of infrastructure they have, attributing this as a factor holding back the scaling of the market. Organization 6 opined that the potential for blockchain being a demand source is massive, citing one of their projects that could calculate and generate carbon credits automatically for immediate sale. They believe the next set of innovations would happen at the project level.

4.3.2 Financing (M1)

This segment outlines the results of findings around the topic of funding of the study organizations and how their activities influence financing for carbon credit projects.

The business model of each organization describes how they earn money or get the fund for operation. Organization 6 makes money by charging commission from their clients. "How we make money is that we take a small cut from bridging, meaning that if you put credits on chain, you leave a small cut with us, and that we also take a cut from people who are basically corporates who want to retire credits."

Organization 3 is funded privately by the founders and partners. They prefer not to seek VC funding because they don't want the dictates of profit by investors to affect their values. Organization 3 also invests in carbon projects through a carbon offset Fund, which is designed to again scale up the amount of capital flowing to carbon types of projects.

Organization 5 hinted at the source of their funding, which is mainly money that would be destined to other tech start-ups like robotics and cloud computing. Organization 2 does necessarily speak with investors of carbon projects at the moment outside of anything beyond strategic potential partnerships.

The respondents continuously established a relationship between their work and increasing financing of carbon projects. Organization 5 wants to "siphon money out of the fossil-based economy and put that money into the new nature-based economy." And Organization 1 stated that the drive is to get as many resources to project farmers and project originators. Organization 7 added that, "it's enabling a more trustworthy form of financing for projects in some of these countries that don't have mature financial systems."

4.3.3 Tokenomics (M2)

Blockchain technology converts records or registries of carbon credits into digital tokens. Here we outline the trend of tokenizing carbon credit from our respondents. Tokenizing carbon credits brings a possibility of trading the carbon credits thereby giving an incentive for participation. The participants in this trading include farmers and others. Organization 1 says,

"by facilitating that, we're essentially making it more likely for people to actually offset in terms of financial incentives." Alluding that tokenization makes liquidation of carbon credit easy and the blockchain application helps disintermediate carbon trading and makes processes swift.

4.3.4 Supply and Demand Dynamics (M3)

Supply and demand are forces that play in the carbon trading markets. The organizations see themselves as forces to open the market, influence niches of supply and influence niches of demand. For instance, Organization 2's immediate impact was to put an additional load of 17 million tonnes or above. They want to continue this to ensure that demand is at least at pace with supply and if possible, outpace it. While Organization 2 works to influence demand, Organization 1 works to "clean up the market and to soak up carbon. And to basically reduce the supply of old credits that are being used for greenwashing etc., that are available for cheap..."

Organization 6 believes the nexus of blockchain for carbon credits could influence the development and drive for carbon credit projects in the long run explaining that when there's on-chain demand drivers, a huge influx of people will try to meet the demand.

4.3.5 Price of Carbon (M4)

Respondents express how their engagement is affecting the price of carbon and helping to increase the price of carbon credits and thereby making a pathway to carbon neutrality. Organization 1 stated the ecosystem "actually helps in terms of making them more aware on a regular basis that this is a thing that they need to cover, because the prices rise so much… in the last year, prices skyrocketed..." With prices going higher, respondents believe that this could go a long way in stimulating or defining the quality of carbon credits. Organization 7 hopes that "the market will put a higher value on projects that are of higher impact."

4.3.6 Cost of verification (M5)

Organization 5 deploys technology to verify carbon stores. Using technology saves cost and time. They narrate how they make this happen by using the Soil Care scanner which they give to farmers. Using a protocol, the results are uploaded automatically unto cloud storage which has greatly reduced cost of verification.

4.4 Governance

Aspects of governance mentioned within the interviews are summarized below.

4.4.1 Blockchain Benefits (A1)

Organization 5 asserted that the blockchain is useful as a communication tool in terms of convincing investors that it's a future-proved thing. They explained that it makes sense of a complex situation – sales verification, certification – in an organizational way. Organization 1 remarked that blockchain is very good in solving coordination issues—a problem the voluntary carbon market currently has—and it's doing so via incentivization.

Organization 2 criticized the legacy carbon market for its inefficiency, slowness, and use of spreadsheets and email for financial transactions in the 21st century. They added that their own

tokens gave their buyers governance rights, as they have a forum where buyers can use their tokens to influence Decentralized Autonomous Organization (DAO) decisions. Organization 4 stated that verification is more accessible through their solution, allowing them to work with individual suppliers. They also posited that blockchain serves in the trading and brokerage of old vintages or credits that were not even any good when they were more recent, for resale again. Organization 7 mentioned surrounding benefits to biodiversity in communities and creating a secure place for trading.

4.4.2 Transparency (A2)

Disintermediation

Organization 7 and Organization 2 opined that blockchain removes middlemen, Organization 7 positing that the reduced friction and transparency benefits the technology brings makes more accessible self-verification for clients. Organization 1 added the permissionless benefits of purchasing carbon credits with the technology. Organization 7 believes the transparency about what it means to be a high-quality project, including methods for choosing the projects and criteria for each individual bundle, which will be publicly available, will set them apart from others. For Organization 6, the whole process, including verification, transfer, tokenization, and retirement of carbon credits is done through the blockchain system.

Data Transparency

Organization 2 asserted that there's a huge amount of data that's generated by the market activity on-chain. They opined that blockchain makes public some hidden information that stifles the growth of the carbon market like the number of live carbon credits, the fair market price for credits, or the buyers and sellers of carbon credits. The transparency, they opined, should ultimately lead to more funds going directly to the project developers because of market disintermediation. Organization 2 hopes to achieve this data transparency by building dashboards and metrics to help standards bodies monitor the carbon market in an innovative way. Organization 1 summarized the transparency of its blockchain technology as transparency in price of carbon credit and a complete description of the projects that generated the credits.

Know-Your-Customer (KYC)

Organization 4 thinks third-party unbiased advisory for their clients on carbon emissions and amount of carbon credits to purchase on-chain is a goal towards ultimate transparency. Organization 3 stated that their clients' decision to go public with information for a full analyses of their carbon emissions lie with their clients. Organization 1 admitted it is hard for them to employ KYC because of multi-credit use of a blockchain account and the anonymity on-chain.

4.4.3 Double Counting (A4)

Organization 4 summarized that blockchain technology from an accounting perspective is innovative in addressing double counting which incentivizes the quick retirement of carbon. Organization 3 posits that blockchain ensures no double counting of offsets, critiquing the legacy carbon registries as running in structured query language (SQL) databases that are hot. Organization 1 asserts that discussions around double counting and double spending are becoming solved with programs because of the self-consistent nature of the system.

4.4.4 Verification Bodies (C2)

Five out of the seven organizations interviewed rely on Verra and/or Gold Standard to issue credits which are then brought on chain by the organizations interviewed. These organizations share similar sentiments that they trust these standards to give the greatest level of assurance for what a verified credit should be. It was discussed from these organizations that Verra and Gold Standard are understood to have a robust verification standard, and a broad range of credit availability.

Organization 2 notes that it's taken a significant amount of time for Verra and Gold Standard to establish credibility in the legacy market, and that its going to take time for the fully on chain protocols to establish the same level of credibility as the Verra and Gold Standard. Organization 3 additionally uses the Global Forest Watch, to do analysis using satellite imagery which can open-source algorithms that are available to monitor at the amount of biomass over the top of forests and to also see if there are things like forest fires that have occurred which may have disrupted the projects.

One organization interviewed registers their own projects, currently working exclusively with farmers to supply regenerative agricultural credits. They discuss financial barriers to signing up with larger verification body as a barrier to entry for suppliers. They compare that with their own organization where the sign-up costs are drastically reduced due to their process of using a desktop audit in lieu of an on-site visit. This organization believes that access to verification is made more accessible through their platform for smaller farms through their use of digital evidence by satellite imagery and other digital verification measures. They also note that "[our organization] was created not out of this theory that there's a demand issue, but it was created out of a theory that there was a supply issue… the reason why we're not just selling… legacy registered credits is because we want to incentivize the creation of new carbon removal projects, we want to build this infrastructure that allows farmers or suppliers … any supplier of carbon removal, to say, okay, I can go to [organization name], and I can get paid."

Another organization interviewed also registers their own projects. One way that agricultural projects are registered is with a digital verification system that farmers update themselves using a soil scanning protocol that. This brings down the cost of sampling significantly and enables access for bringing on new projects. This organization also supplies other types of credits and works with the supplier to try and find a verification process that works with them, and can be peer reviewed and scientifically accepted in order to obtain metrics that can be built on. Over time this organization can then change the type of credit that they're able to issue.

4.5 Infrastructure and Technology

The following section touches on the aspects of infrastructure and technology discussed in the interviews conducted which are relevant to the topics of this thesis.

4.5.1 Type of Technology Used (I1)

Six out of seven of the organizations interviewed already use or plan to launch on Polygon. The seventh organization plans to work with the Cardano Foundation blockchain network. Polygon is popular because it is considered energy efficient due to its use of the Proof of Stake consensus mechanism. More reasons why organizations choose Polygon are that it is cost effective and

there is more availability of developers to hire who know how to use Polygon. See section 4.2.6 Emissions for Blockchain (E2b) for reported emissions calculations on the Polygon network.

4.5.2 Contracts (I2)

Smart contracts help automate transactions without the need for a human agent of verification. All the organizations interviewed use smart contracts written in the solidity programming language.

4.5.3 Usability (I3)

The respondents established that blockchain is new and especially at the forefront of Web3. This is a pain point for potential users. Organization 4 believes that blockchain has a very strong case for providing ultimate transparency, and that as an increasing number of people get comfortable with it and it becomes more user friendly information will be easy to access.

Other respondents spoke in this light. They believe blockchain helps to monitor the process of what they purchase. And added that it improves traceability and accessibility. Describing accessibility, Organization 1 mentioned, "blockchain makes the carbon credit market accessible. With a mobile blockchain wallet… you don't need any kind of intermediary."

Organization 2 and Organization 4 highlighted a general view of continuous improvement specifically to improve the usability of the platforms. Organization 3 envisions a plug and play website where users can log in and offset without a need for additional wallet accounts.

4.5.4 Barriers to Adoption (I4)

The respondents identified 5 points as the barrier of adoption blockchain for carbon trading.

1. The need for energy and energy efficiency: Being that blockchain requires constant energy supply to keep the nodes running.
2. Demand on chain: Organization 7 identified that bringing in buyers to the demand end is a barrier because some organizations do not have a culture of offsetting their carbon footprints in the past. Organization 7 thinks clients are comfortable operating on-chain but may necessarily know how much they should offset. There is a need for educating buyers. But Organization 3 has a slightly different opinion by stating that, "the biggest barrier, I think right now, is building up demand on-chain, having companies being comfortable sourcing their credits on-chain, part of that involves working closely with the standards bodies like Gold Standard and Verra. The partnerships aren't fully established between the standards bodies and the bridging entities."
3. Knowledge about technical domains. The domains of blockchain and carbon credits are individually complex to grasp. The organizations identified that getting people to adopt the model is affected by the amount of technical knowledge needed to participate. For Organization 6, it gets more complex as they also get involved with the building and energy management ecosystem. Organization 6 calls this hybrid domain of carbon credits, blockchain and building management the Organization 6 trilemma. The organizations stated that apart from the low knowledge available, there is also the misinformation about blockchain and carbon credit which has made people skeptical. There is a skepticism that neither carbon credits nor blockchain does any good and that a combination of both can

hardly be of economic profit. There is the general doubt of something new especially if it threatens the old cultural, societal, and industrial models. Organization 5 stated, "I guess the main risk is that people who are heavily invested in certain areas of the economy can use the weak parts of the blockchain to try and destabilize confidence in emerging markets," Organization 6 expressed the same point, "… people don't want to believe that you can build things in in sustainable ways that make money but it's just like a concept that doesn't exist."

4. Funding, investors, and demand: Not all the organizations considered funding for scaling their businesses as a challenge. Organization 3's model is not interested in VC funding. But Organization 6 sees the lack of understanding of the domains as a barrier of adoption not just to users but to potential investors.
5. User friendliness: The issue of digital interfaces as a platform for transaction is a barrier. There is a need to create digital interfaces that help users navigate the complexity of purchasing, trading, or retiring carbon credits. Organization 2 noted that not everyone knows how to get money onto digital wallets.

4.5.5 Security (I5)

The respondents believe there is no other tool or technology that currently provides the security of blockchain. They stated that the security of blockchain is based on the following elements or operation of the technology: a backup of the website is saved on a decentralized hosting provider, audited smart contracts are checked by a third party for vulnerability to hacking, a protocol that requires 3 out of 5 consensuses among the core team to give permission for any execution (Organization 2), and distributed nodes for operating blockchain are in different locations.

4.5.6 Survey Results

The survey targeted sustainability aspects with respect to the studied organization. The scope of the enquiry in this section are energy use, hardware use and disposal, and data storage regime. All organizations studied responded that they would not require exponentially increasing data storage or energy consumption. Organization 2 states that they would need even less energy after Ethereum moves to PoW as explained in section 4.2.7 Energy (E3). None of the organizations report owning a server farm. Two organizations stated that they use cloud-based data storage. Organization 6 estimated to use their hardware for at least 10 years and tries to replace broken parts or recycles the hardware at the end of life. Organization 5 uses their hardware for a maximum of five years and donates them at the time of replacement. Overall responses from this survey were lacking in detail.

4.6 Deficiencies

Respondents made points about the deficiencies of the old and new ways to trade carbon credits as outlined below.

4.6.1 Legacy way of Blockchain Trading (D1)

The legacy process of keeping records of carbon credits, trading carbon credits and retiring them is characterized by an underlying need for mediation. The mediation layer causes a slow,

analog and mostly manual process, a low incentive for developing carbon projects and innovation, and opacity in the records and processes.

4.6.2 Blockchain Enabled Carbon Trading (D2)

The emerging system of trading carbon credits with blockchain has the following deficiencies: little or no standards among technology operators, the need for more complementary or associated technology for example for carbon foot printing and accounting, the fast-changing landscape of blockchain technology, and the novelty and complexity of the blockchain ecosystem.

4.7 Future

Throughout the interviews topics related to the future (coded F) of the carbon markets intersection with blockchain were coded for and elaborated on in the sections below.

During the course of the interviews, the question was asked "Where do the blockchain based carbon traders see themselves in 10 years or more?" The responses below came from this question directly as well as mentioned at other points during the interview. Responses most relevant to this thesis and reported on below revolved around the topics of trading beyond carbon, supply chain innovation, disintermediation from brokers and scaling up to an entirely on-chain carbon trading system.

Interviewees from six organizations interviewed responded to the questions by discussing increasing the diversity of credits to additional markets that the organizations are not currently involved. Holistic markets beyond carbon being traded on the blockchain system were also mentioned as a possible future as reported by these organizations enabled by transparency and trust that blockchain allows. Organization 5 is hoping to see the future of the market move investment money out of other industries such as petroleum into the new nature-based economy this application is helping to create.

Room for improvement with the blockchain trading market was discussed by four organizations interviewed. An innovation that is hoped to be seen by these organizations in the future is a solution that is more digitally monitored and digitally reported which could satisfy needs of a project and be able to originate more credits straight onto the blockchain. The IoT project mentioned in section 4.2.1 Types of Carbon Credits (C1) is an example of this. The evolution of digital monitoring reporting verification is regarded by these organizations as something that is making verification more accessible. It was noted by one organization that the technologies need to be proven and accepted by the standard bodies to make the technology more accessible.

Disintermediation from brokers is discussed when Organization 2 mentions that current issues with the demand side of the market is that it is limited due to a broker dominated market, and that the future of the blockchain market comes in to remove these problems. They go on to talk about how Verra registry retirements of carbon credits are not done by the consumer but by an intermediary who charges a fee and muddles transparency further. They do not foresee the legacy market surviving for another ten years. Organization 1 had similar sentiments with the above, saying that today the market is only partially accessible due to the structure of the legacy market requiring brokers, and that the future will be less of a monopolistic market for traders.

Organization 3 mentions that beyond what is being emitted today, carbon removal will be needed still to mediate the carbon emitted previously. Organization 4 emphasizes that voluntary buyers have a benefit now of being involved in the market early on while carbon is currently undervalued. They also note that even in the future where voluntary buyers fully decarbonize, there will still be a need to continue to withdraw carbon from the atmosphere to reverse emissions damage. The organizations interviewed emphasize that scale will need to be increased dramatically to incentivize climate action to meet the needs of the future.

Organization 6 believes scale is already happening to change the market considering the growth rate of the current market using blockchain. Organization 3 also thinks that the future of the carbon market will be off chain, quoting that blockchain "is an infrastructure that enables a far more efficient, transparent, robust carbon market." Organization 1 thinks that crypto and Web3 is going to be a complete revolution for equitable access to finance around the world, and that we have yet to see the full scope of what the technology can do.

4.8 Organization Specific

While coding, organizational specific information came up throughout the interviews. These were best summarized in a table which can be found in Appendix A4.

5 Discussion

In this chapter we discuss our findings from the results, presenting our analysis of the SP aspect of the sustainability lens, followed by the discussion around the secondary research questions and primary research question. A section outlining our post-research reflections and finally recommendations for further research are also included below.

5.1 SP Analysis

While the point of trading carbon credits boils down to removing or avoiding carbon emissions from the atmosphere, we use the 8SPs as boundary conditions for a sustainability lens to determine whether the application of blockchain is violating or contributing to upstream causes of unsustainability within the systems relies on. We first look at the ecological principles which according to are that:

In a sustainable society, nature is not subject to systematically increasing:

1. concentrations of substances extracted from the Earth's crust;
2. concentrations of substances produced by society;
3. degradation by physical means; (Broman and Robèrt 2017, 23)

Ethical conditions for the application of blockchain lies with the users' motive. Using blockchain to scale up and finance nature-based solutions for more public access to carbon removal or avoidance attempts to minimize societies violation of the ecological SPs. While trading carbon credits aims to do less harm it cannot be overlooked that the application still relies on an energy system that in some regions are still reliant on fossil fuels. Due to the ambiguous nature of the current energy regime and the implications of the blockchain system to be on an increasing curve of energy use, it is difficult to separate the blockchain system from the unsustainability of the current energy system. The blockchain system when used for trading carbon credits produced from renewable energy projects does have the potential to accelerate the effective transition to a more renewable system. So while the current unsustainable use of the energy system is in violation of SP1 if the blockchain organization uses fossil fuels, and SP2 when those fossil fuels create emissions, balancing short- and long-term success is an aspect of systems thinking to consider. It is also important to note that a fully renewable system does not guarantee SP alignment. The organizations interviewed have focused on using the PoS system which is orders of magnitude lower in energy consumption than the PoW system, however at this point efficiency does not equate to sustainability. The industry is moving in the right direction; however, the system inherits the problems society still currently faces with the current energy system.

The carbon credits system perpetuated by blockchain is an attempt to contribute to the financing of nature-based solutions that reverse environmental degradation and, in some cases, go beyond carbon. The attempt to use carbon as a baseline for value to enable the restorative or environmentally protective projects is in alignment with SP1, 2, and 3. Carbon credit projects supported through the organizations interviewed support ecosystem health through enabling multiple methodologies of carbon removal projects. Co-benefits and ecosystem services associated with creating carbon credit projects are enabled, leading to more benefits that are harder to valuate but could be enhanced through the blockchain trading system. As blockchain becomes more innovative in the future, there is a possibility for trading other ecosystem services

such as biodiversity, soil health, or clean water. While carbon removal or abatement projects can be seen as treating symptoms of an unsustainable society, a systems perspective helps keep in mind that progress is being made by scaling up access to solutions. In combatting climate change, supporting these environmental innovations could be a pathway to a transition while phasing out carbon intensive processes.

It is important to understand the interrelationships between the social and ecological systems and how human society is degrading the earth's ability to support life, to be able to address the sustainability challenge strategically and create fully sustainable solutions. Analyzing the social SPs proves more challenging for this application, as the limitations of our research did not extend into the communities where carbon credit projects take place. The social SPs are:

and, in that society, people are not subject to structural obstacles to:

4. health;
5. influence;
6. competence;
7. impartiality;
8. meaning-making. (Broman and Robèrt 2017, 23)

From the analysis of our results section, it was identified that the blockchain application for carbon credits does not address social sustainability as defined by the 8 SPs. While there are positive contributions to the social SPs as described below, the applications' uses to lessen structural obstacles within the systems that this application is nested are not specifically addressed by using blockchain.

One positive contribution identified is that while the purpose of the application is targeting the ecological SPs, environmental health translates to social health as well. An example of directly influencing SP4 concerning health is the cookstoves project. Areas where indoor open flame cookstoves are prevalent diminish indoor air quality which leads to respiratory health problems, disproportionally affecting women who cook the food. This project is a holistic view of what the blockchain system could be, where data is brought directly on chain by the advanced cookstoves supplied. Human and environmental health are preserved, and the emissions calculated by the advanced cookstoves to have been reduced are sold on chain which finances the project for the individuals who need access and could not afford the new cookstove otherwise. The aspect of having verified data brought directly on chain to market strengthens trust in the system where buyers know that the credits purchased are calculated accurately and transparently.

While we only interviewed one organization that is considered a decentralized autonomous organization (DAO) this can be used to discuss SP5 where both violations and alignments are identified around the governance mechanism. Influence is supported for all parties in the DAO system via collective discussions of proposals on systems change or development as well as right for all (with tokens) to vote. However, those with more governance tokens have more voting power than others. This means that people are not systematically hindered from participating in shaping the system they are part of, but there is a way to use financial superiority to have more power through obtaining more governance tokens.

Although a learning curve may be present for buyers or sellers using the blockchain system to purchase carbon credits, this system is closer to aligning with SP6 in a way that is far superior to the legacy system, but it still does not mean to address structural obstacles to competence.

Examples of alignment include how using the blockchain system is meant to allow equal access in the voluntary carbon market, compared to the legacy system which utilizes brokers and intermediaries to have access to the market. Concern regarding the rebound effect was considered by the authors, and from the results section was thought by the interviewees to not influence buyers 'license to emit more'. The interviewees regarded buyers' competence to increase after education that comes throughout the process of purchasing carbon credits. This education influences mitigating emissions at the source and leads to a more informed buyer who considers both cost of emissions if offsetting, as well as environmental implications.

SP7 regarding impartiality states that that people are not systematically exposed to partial treatment from structural obstacles (Broman and Robèrt 2017, 23). The blockchain application gives impartial access from a sales point of view; anyone can access and purchase any credit of their choosing through the organizations interviewed. Conversely one could also argue that blockchain creates new obstacles to impartiality through being hard to understand and very tech savvy, excluding many people who do not grasp how to use it. From a supplier's point of view, partial access is given by the organizations interviewed who rely on Verra and Gold Standard. While these verification bodies are considered the most reputable with their methodologies as well as having the largest volumes of carbon credits to supply, the heavy reliance on the legacy carbon market for carbon credits suggests that the supply of projects is limited to what these bodies can verify. While the bridging of carbon credits solely from these registries into the blockchain adds to the credibility of the carbon supply chain, other carbon verification schemes may not get the attention that they deserve. Also, non-disclosure of current emissions reduction by corporate buyers would make it difficult to prioritize, in the most ethical way, the sale of carbon credits to which buyer especially when supply is unable to meet demand. Parties that are not doing much to reduce their own carbon emissions, which have the same free rights to purchase carbon credits as those whose practices are environmentally friendly, can buy out more credits (especially when they are more financially buoyant) than the latter.

The open access to voluntary carbon markets that blockchain technology offers could contribute to or violate SP8, meaning-making, depending on how the technology is used. This is because individual meaning can either contribute to or be an obstacle to collective meaning. This is true for the blockchain system because, although the use of the technology has the potential to enhance the participatory element of engaging people into a common purpose of buying and retiring credits for carbon removal, a blockchain account has multi use besides retiring carbon credits and DAOs which hosts this technology infrastructure currently possess some governance gaps to check these alternative uses. On the supplier's side, the application could enable projects which may not have otherwise taken place due to financial restrictions, and potentially engage suppliers in purpose to work together towards a common goal of carbon reduction. Together with collective meaning-making, blockchain's relevance in the recent community of people in Web3 (the generation of the internet only operating in a more decentralized environment) for creating platforms for co-learning, co-creating, and reshaping the systems the community of people Web3 are a part of, is still subject to validation.

The current energy consumption of blockchain for carbon markets analyzed in the context of a general unsustainable energy ecosystem does not align with the SPs, as exponential growth in computing usage currently correlates with electronic waste, which violates SP1, SP2, and SP3. Although it has the potential to become a leverage point for accelerating carbon removal as well as energy systems change through financing renewable energy projects, from an SP point of view a shift to renewable energy does not guarantee SP alignment, especially if the energy

demand is growing—which risks other SP misalignments too. Besides shifting away from fossil fuels, from an SP perspective in the computing sector in general will need to come to terms with the sustainability issues of energy demand and electronic waste before making claims of sustainability. This is not a blockchain issue but a problem blockchain shares with computing technology in general.

Except for supporting renewable energy credits, the carbon market does not apply upstream thinking to the systemic issues of carbon emissions at the source. The system does apply upstream thinking to creating a healthy environment, attempting to valuate things from ecosystem services that currently do not have a price associated with it. Ecological sustainability could be further enhanced through new market innovations discussed in the futures section of the results chapter, where interviewees referenced trading beyond carbon as a possibility to bring further value and variation to the market. The interviewees referenced that they believed the future of the market to reach beyond carbon and have a more holistic view, where trust in the market that these credits are doing something towards sustainability will permit more abstract types of credits such as biodiversity and clean water credits to be valuated and tradable in the market.

The intention of the blockchain application with carbon credits is to support scale and access to carbon removal or avoidance. It is recognized by the authors that at times the solutions provided in the carbon credit market focus on solving symptoms of problems instead of addressing problems at the root cause. From a systems perspective, the authors see that the application of blockchain in voluntary carbon markets provides an opportunity for buyers to educate themselves on sustainability and participate in a market that has the potential to accelerate the transition of society into the sustainability future. But it is the intent behind the use of the technology that can inform whether it contributes positively to social sustainability or not.

5.2 Secondary Research Questions

This section of the chapter seeks to answer the secondary research questions we posed when structuring our research which are:

1. Could carbon offsetting in the voluntary carbon credit markets via blockchain based technology potentially increase the supply of carbon credit projects?
2. Does the use of blockchain technology strengthen voluntary carbon buyers' commitment to net-zero?
3. Does the use of blockchain technology contribute to the production of high-quality carbon credits?
4. Does the use of blockchain technology promote fairness in carbon trading?

5.2.1 Could carbon offsetting in the voluntary carbon credit markets via blockchain based technology potentially increase the supply of carbon credit projects?

Based on the response of some organizations, blockchain enabled with the internet of things (IoT) could be used to keep record of carbon offset reductions. Self-verification of these projects by the project developers means time and resources are saved during the verification process. As seen in some application of blockchain for verifying credits from nature-based solutions, the cost of verification is greatly reduced when the technology is applied in

conjunction with other hardware technologies to test soil carbon. From a cost accounting perspective, operational cost is an important consideration when discussing scaling a business. Tokenization of carbon credits is also an incentive for farmers to sell their credits as quickly as possible since the elimination of middlemen correspondingly eliminates the need for hoarding due to hedging against price risk.

It is unknown, however, what the marginal impact the disintermediation of the voluntary carbon market has on the supply of capital-intensive projects like renewable energy systems. Although the disintermediation of middlemen will bring more stakeholders into the market, it is still under probability whether these new buyers or players will engage in activities that favour the supply side of the voluntary carbon market supply chain. For instance, the benefits of liquidity that tokenized carbon credits gives project developers could be reduced if buyers are only purchasing tokens to create artificial scarcity to favour the price increase of carbon credits. This artificial scarcity could tend towards reducing turnover for, as an example, nature-based solutions, and put more funds in the hands of the buyers on-chain than in the project developer's hand.

Six organizations interviewed are still representing older vintages of credits from carbon registries like Verra and Gold Standard, which have yet to be purchased and transferring them on-chain. Although the organizations interviewed mentioned these carbon registries have huge volumes of carbon credits, the heavy reliance on the legacy carbon market for carbon credits suggests that the supply of projects is limited to as much as these carbon registries can verify.

There is also the dilemma of pursuing the production of a high-quality carbon or scaling the system infinitely, as either choice seems to be inversely proportional to the other. Credits are seen to be more valuable by different organizations or buyers for different reasons. For example, credits from a renewable energy project may be valued for its high permanence, but are capital intensive to scale infinitely, compared to credits from a forestry project which may offer more co-benefits but a with higher risk of losing its permanence (due to forest fire or other disaster). To generate credits with a range of co-benefits, organizations applying blockchain technology may find there's a need for them to work with projects that involves government at the local level. This would involve many stakeholder engagements that may add to the complexity of project management and is potentially time consuming, from a scaling point of view. In this light supply is still constrained by externalities beyond the blockchain system.

One feature of blockchain which has the potential to affect supply of climate action project is the immutability of the blockchain records. Unlike legacy carbon registries which require project developers to disclose any material eventualities that occur on verified projects, e.g., burning of a part of a forestry project, to adjust the value of credits issued, on blockchain a buffer of carbon credits may be required to annul or cancel the effect of any such eventuality given the immutability of the records in the system. This buffer is an excess supply of carbon credits which could be generated from the same or multiple projects. For a forestry project, for instance, insurance by a buffer from another project or project location is a good way to manage concentration risk (in this case, the potential loss in value of carbon credits when the exposure to eventualities like forest fire is all in one project/project location). It is important to note, however, that this does not take into consideration the cost of developing the excess carbon credits.

Toucan's ambition to use their blockchain platform to mop up carbon credits as much as possible from the legacy market, is an incentive to rekindle projects in the old system whose

carbon credits may be perceived as low-quality by the market. From Toucan's perspective, the conventional method of defining a quality carbon credit does not compare different types of projects adequately. Their solution is to have pools that group types of carbon credits with similar attributes together to help create varieties of credits that would meet the demand of the growing number of stakeholders with different interests in the markets but also help to improve the liquidity of the carbon credit market. Tokenization of carbon credits has made it possible for project developers to hold digital certificates of their carbon credits that is liquid, hence increasing their potential to develop more carbon projects. However, this should be followed by strict verification to ensure the quality of carbon credits generated is improved over time.

5.2.2 Does the use of blockchain technology strengthen voluntary carbon buyers' commitment to net-zero?

Net-zero refers to a state in which GHGs, such as CO2, emitted are balanced by removal. The Science Based Target Initiative (SBTi) designed the Corporate Net-Zero Standard to help organizations make plans to reach short, medium, and long-term goals. Net-zero is one strategy to abate climate change and reach a decarbonized economy. Voluntary compliance with the Net-Zero Standard instructs organizations wishing to decarbonize to develop a roadmap to reach net-zero emissions. After the organization has achieved emissions reductions, then unavoidable emissions must be neutralized (offset). Neutralization involves investing in projects or technology that remove or abate carbon emissions. Purchasing carbon credits is one way of neutralizing.

Blockchain for carbon credits does not inherently increase organizations commitment to being environmental, however, if the organization has already imbued values for climate action and has committed to something such as the Net-Zero Standard to reach carbon neutrality, then the application of blockchain with carbon can be a great enabler. If organizations are to purchase carbon credits to neutralize then they must find carbon credits that are accessible and accounted for. Driving the wheels of society towards net-zero, blockchain for carbon trading can help meet the following recommendations by The Oxford Carbon Principle and TSVCM:

- Transparency and accessibility to high quality carbon credits.
- Stimulating the market for robust supply and demand dynamics which ensures that there is a supply of carbon credits for the increasing demand.
- Data infrastructure for instance, access to registries on a digital platform.

Blockchain technology has the potential to strengthen buyers' commitment to Net-Zero as it makes offsetting accessible to individuals and organizations that are committed to environmental goals.

5.2.3 Does the use of blockchain technology contribute to the production of high-quality carbon credits?

This question was informed from our original framework generated from reviewing the Oxford Carbon Principles and the Taskforce on Scaling Voluntary Carbon Markets (TSVCM) and perpetuated by the organizations interviewed having varied responses to the question of how they would define a high-quality credit. The Oxford Carbon Principles, TSVCM, and verification bodies such as Verra and Gold Standard, all reference the need for high-quality credits to be available in the carbon market.

Commitments to developing 'high-quality' credits may be an ambiguous term because different bodies accounting and verification methodologies vary and because credits' co-benefits (such as community economic development and biodiversity protection) are seldom well defined (Blaufelder et al. 2021). The definition of quality credits can generally be summarized by the International Carbon Reduction and Offset Alliance (ICROA) accreditation principles which dictate that carbon credits must be real, measurable, permanent, additional, independently verified, and unique (ICROA 2021). The common thread throughout the interviews and literature was additionality, permanence, and co-benefits as qualities which created more value for a carbon credit. While the term high-quality is variable due to different agencies having different methodologies as well as buyers assigning value to the credit, maintaining market integrity through transparency of what each defines as a high-quality credit will be paramount to ensuring quality as defined by the buyer, since buyers value attributes differently and ultimately set market prices.

TSVCM references that market concerns relate to integrity and quality. The task force reports that low prices lead to worry over quality, certain methodologies require updating which indicates that some projects may no longer be additional, and that old credits reduce the integrity of the market. Lack of transparency and thus credibility concerns in corporate use of offsetting and in point-of-sale products affect what is considered a high-quality credit (Blaufelder et al. 2021). Realizing integrity within the market now means that old projects with outdated methodologies need to get off the market, and new projects which are transparent and consistent in their methodologies need to replace them. This switch is something that blockchain systems has great potential to contribute to when it relates to creating a high-quality market. Toucan specifically is trying to mop up old vintages to make room for the new credits, but all the organizations interviewed are contributing to the further reaching market of carbon credits being available to the voluntary market.

Five out of seven organizations interviewed rely on Verra and Gold Standard methodologies since these verification bodies use established methodologies. The blockchain technology is then applied for access to the voluntary market as well as scale. While these verification bodies are seen as the most reputable in the industry it is limiting which types of projects will be brough on chain to their methodologies. The organizations that use their own methodologies such as Nori and ONCRA accept that their methodologies need to be transparent for suppliers and buyers to establish how quality is determined. There is a consistent theme of needing to scale up and get rid of the old credits to continue to refine current methodologies and strengthen them for the integrity of the market.

Nori's application uses a different take on the meaning of additionality which brings a unique leadership to the market. Nori has a clearly defined methodology that uses the ICROA standards of real, measurable, permanent, additional, independently verified, and unique credits but deviates with their definition of permanence and additionality. They challenge the ICROA standard of permanence being accepted for 100 years and instead contract their suppliers to ensure a permanence of 10 years, and they include a policy to safeguard against reversals by ensuring a monitoring practice and insurance program for covering any potential carbon re-release. This implementation highlights the fact that change is needed urgently within the climate space. Nori also challenges additionality. The ICROA definition states that neither the project nor the carbon removal would have happened without financial support from the market. Because Nori is using regenerative farming as the basis for their carbon credit supply, they want to support solutions that are abundant and enable access to ramp up scale for farmers. Nori

defines additionality as incremental and measurable changes in carbon removal year over year (Nori 2022) This approach deviating from the major verification bodies of Verra and Gold Standard allows for additional credits to be supported which would not have made it on chain by Verra and Gold Standard methodologies, but which are still supported scientifically.

From a systems perspective, the carbon market will need to scale up from a determined baseline and have varying degrees of quality available to achieve the scalability it needs to have an impact on the climate crisis. Credits will need to be supported by a science-based methodology, which is reported on transparently, supporting integrity in the verification process, and underpinned by the basic qualities of a carbon credit being verifiable, and real. Things such as co-benefits may bring the price up of a credit, but many different price points are needed for different types of buyers. If the market is to scale to the degree necessary to make a meaningful impact on the environmental crisis, varying degrees of 'quality' starting from an established baseline will need to be available for a variety of purchasers.

Ultimately one tonne of CO2 removed or avoided adds up for a better future. Because the market needs to scale up so much, offering a wide variety of credits with a more transparent methodology, sales structure, and availability of purchasing, the application of blockchain does move the carbon credit industry closer to sustainability. There is complexity within the carbon market around trust, but this is something that blockchain attempts to solve. Verification of carbon removal or avoidance is perhaps the hardest part to quantify, however promising technologies from the blockchain system have potential to create a more efficient measuring structure which would have all the data on chain and enhance trusted methodologies. This is something that blockchain innovation attempts to solve, with things like the cookstoves project and remove sensing helping with integrity of data as mentioned in section 4.2.1 Types of Carbon Credits (C1), but there is still a human aspect of verification that is difficult to quantify and can lead to some blind spots.

Due to the variable nature of the term 'high-quality' it is difficult to give a concrete answer regarding whether using blockchain within the carbon market contributes to the production of high-quality carbon credits. The innovation using blockchain technology helps to use up old vintages of credits which are not up to the current methodologies standards which in turn increases the integrity of the current supply while increasing access to scalability and offering different price points for different buyers. From analyzing interviewee responses to the question regarding high-quality credits it is believed that if a carbon credit is transparent in its methodologies and adheres to baseline standards, carbon credits will be acceptable on the market and then it up to the buyer to determine what level of 'quality' meets their standards and needs based off additional benefits.

5.2.4 Does the use of blockchain technology promote fairness in carbon trading?

Fairness has been defined as "the organization of economic activity to the benefit of users in such ways that they reap the just rewards for their contributions to economic and social welfare and that business users are not restricted in their ability to compete (Crémer et al. 2021). From our study, tokenization of carbon credits in blockchain technology gives an incentive for participation in the carbon credit market since tokenized carbon credits are sellable in the carbon market. This is especially significant for the project developers who, formerly in the legacy carbon market, would hold concerns about what a good price for carbon credits in the open market should be. Project developers need to be sure they are getting good value for their work

before making the decision to sell to arbitrageurs who are buying credits just to resell immediately for profits. Arbitrages by brokers could sometimes leave the project developers with little margins in projects, but tokenization of carbon credits gives project developers more agency on the price of carbon credits, thus offering an incentive to participate in the carbon market.

Response from one of the organizations under study also showed that blockchain technology has influenced trading of carbon credits in a way that can be likened to trading in the e-commerce sector, where "everyone wants to be online… everyone wants [things] to happen quickly and just as you can buy stuff online much easier, you can also trade [carbon credits] much easier online." This suggests an inclusivity feature of blockchain technology where, from an entry point, participation in the market to trade carbon credits is open for all, including individuals and corporates. This is unlike in the legacy carbon market that is partially accessible due to brokerage by middlemen.

However, the permissionless use of blockchain infrastructure without some level of due diligence or know-your-customer (KYC) check on buyers of carbon credits may give room for corporates to indulge more in practices that contribute to global sustainability challenges. From the accessibility offering of blockchain, buyers, irrespective of their size or contributions to reducing their carbon emissions, have the same power and influence in the carbon market. This is sensitive for two reasons.

First, consider that for DAOs in decentralized finance markets, a common governance process involves raising a proposal for a development or change, which is then discussed within communities of interests (e.g., Discord) and influence (e.g., the organization's forum for formal discussion and debate). Voting power on proposals that the community is on board with is determined by the number of tokens owned, sometimes on a one-to-one token basis. For corporates who have done little or nothing to reduce their own carbon emission, this "democratic" voting system that discredits corporate behaviour towards internal carbon reductions in its governance model creates an incentive for some buyers to game or exploit the voting system to benefit themselves, at the expense of other buyers.

Secondly, as buyer participation in the voluntary carbon market continues increases, non-disclosure of current emissions reduction by corporate buyers would make it difficult to prioritize, in the most ethical way, the sale of carbon credits to parties with climate-friendly practices especially when supply is unable to meet demand. Retiring carbon credits is not the only reason why people purchase carbon credits, so clients' carbon emissions reduction disclosure is important for ensuring that buyers that are more environmentally friendly in their practices are not limited by "market forces" when trying to meet their short-term net-zero targets in full and in time. Also, disclosure policies, if properly developed, could provide data for third party advisory to determine or validate how much credits are required for offsets. Such a data service provision has the potential to regulate the demand for carbon credits in terms of moving towards an equilibrium position the demand for carbon credits and the demand for retiring carbon credits.

Amongst the organizations studied, the assurance that carbon credits from popular registries like Verra and Gold Standard have been duly verified comes from a place of trust, given their long-standing reputation in providing a broad range of credits in the carbon market. These carbon registries were also mentioned as having large volumes of carbon credits, which influenced the blockchain organizations to source carbon credits verified by them. While the

bridging of carbon credits solely from these registries into the blockchain adds to the credibility of the carbon supply chain, over-reliance on them may cause other carbon verification schemes to not get the attention that they deserve.

The carbon credit market system is based on trust which, according to one of the organizations studied, is a tenuous trust. To illustrate, compare accounting for producing financial statements in organizations with accounting for producing carbon credit certificates. In the former, trust in a third-party auditor for verifying the organization's account is preceded by an internal audit that employs similar standards as the auditor's standards. In carbon accounting, however, trust in the third-party auditor is the only validation of credit quality. Using this logic, until the methodologies used by new carbon verification schemes have been tested by organizations deploying blockchain solutions for the carbon market, they should not be waived aside as not trusted. Doing so may decrease participation of players in the carbon verification space, strengthening the monopoly of carbon certification schemes.

This monopoly of verification is risky for the blockchain building end of the carbon market if the legacy carbon registries go all blockchain. Although the agility of the new players in the blockchain-VCM space currently gives them a competitive advantage over the legacy carbon registries (this is inferred by a comment in our interviews that Verra and Gold Standards have been talking about blockchain and carbon credits for a long time but never acted), the long reputation of the latter in the carbon market should be given due consideration in competitor analysis, especially if their potential move to blockchain becomes backed by regulations.

5.3 Primary Research Question

This chapter is structured based on the analysis of the results section to answer the main research question:

"*What are possible roles of blockchain technology in carbon trading and voluntary carbon markets through a sustainability lens*?"

It has been observed by the authors the roles that blockchain plays to address the sustainability challenge can be distilled into three factors which are: enabling markets, transition in the information and technology sector, and supporting opportunities for change in the socio-ecological system. Limitations of each section are also discussed within.

5.3.1 The Role of Blockchain in Enabling Markets

In the short term, blockchain helps to disintermediate the carbon credit market, facilitating access to the voluntary carbon market and increasing the amount of capital flow to project developers. Blockchain smart contracts, programs whose terms are recorded in a code enables disintermediation. They are automated actions that can only be executed when a set of condition is met. The expectation is that more stakeholders participating in the market will raise the credibility of the market. Although building demand on-chain is still a cause for concern of corporate buyers, given the reported gaps in partnership between the traditional verification bodies and blockchain bridging entities, the latter's sourcing of carbon credits adds integrity to the blockchain- voluntary carbon market- system. Also, as the market grows, there will be a need for due diligence pre-entry into the blockchain-VCM system to ensure fairness in the market on-chain as defined by (Crémer et al. 2021).

On the supply (project developer) side, tokenization of carbon credits in the blockchain system creates liquid assets on-chain which has the potential to increase availability of funding for carbon removal or avoidance projects. Project developers can more easily access their financial rewards for contributing to carbon credit projects, giving them continued confidence in the practice. Gains in the price of carbon credits from tokenization have the potential to attract new investment from different players, which could result in the generation of a wide range of carbon credits projects. On this, the market could benefit from a growth of carbon credits that range in terms of their price and perceived quality, as this will help set the market reference price for project developers' and investor's Return on Investment (ROI) projections. However, this is conditional upon a market consonance on the common definition of a quality carbon credit and quality of verification methodologies.

In all, the ease of market access and increase in capital flow to project developers from disintermediation, and increased market liquidity from tokenization are benefits that blockchain brings to the carbon market. These could potentially help to finance the market for carbon project development. Governance systems off-chain, market consonance on the definition of quality credits, and quality carbon verification methodologies are additional factors required for the blockchain application to help VCMs achieve a meaningful increase of scale necessary to positively impact the sustainability challenge.

5.3.2 Transition via Information Technology

Blockchain is a recent technology which is advancing the frontiers of the emerging Web3. Technology on its own, is a tool that can be deployed for good or may cause harm if design factors are not well considered. Designing for factors such as the SPs can become a way for technology to solve problems. Blockchain builds on previous technologies, but what is even more unique is its feature of enabling other technologies to be built upon blockchain further still.

Using blockchain for carbon credit trading also presents us with many scenarios of interaction between different technology as presented in the corresponding table for results section 3.8 Organization Specific, Appendix A4. Flowcarbon has collaborated with Celo, a recently launched blockchain project to develop open on-chain market infrastructure. KlimaDAO and Offsetra use Toucan Bridge and bonding to migrate carbon credits on-chain. ONCRA and Creol build connections between existing digital technologies and blockchain in order to seamlessly bring data on-chain using IoT. ONCRA uses satellite imaging to enhance verification of carbon credits, and Creol uses radio technology within their building management devices to communicate within small systems. There is a crosspollination of features between technology, forming new constellations that were absent before the application of blockchain technology. Working with verification bodies such as Verra and Gold Standard, blockchain projects can digitize these existing registries to make them digitally accessible. Blockchain technology is an infrastructure with the potential to enable further innovation needed to address the urgency of climate change and improve interaction between unlinked systems that can benefit from interconnectedness.

Sustainability, and by extension, the climate challenge is systemic, with complex interrelated systems. The root of the sustainably challenge is based in society continuing to follow unsustainable structures. To shift from a well-established structure, a strategy is needed. Trading carbon credits can be viewed as a short-term strategy in the larger global strategy towards decarbonization. Carbon trading is a transitioning phenomenon as explained using the

Three Horizons framework and the blockchain application is seen here as a disruptive phenomenon which has the potential to bring about the emerging H3 future. Layering blockchain with carbon trading can increase the effectiveness of carbon trading as a framework to reach net-zero.

5.3.3 Blockchain Supporting Opportunities in the Socio-Ecological System

The case for blockchain supporting opportunities in the socio-ecological system stem from its root purpose of allowing the voluntary market to participate in purchasing carbon credits which provide financial incentives for carbon removal or avoidance projects as identified in results section.

It is identified that the application of blockchain with carbon credits supports the transition towards sustainable solutions through applying a systems perspective, considering the scale and quantity of carbon needing to be removed in the Results sections 4.2.8. and 4.3.1. The TSVCM determined that to meaningfully support a 1.5°C pathway, voluntary carbon markets need to grow by >15x by 2030 (Taskforce on Scaling Voluntary Carbon Markets 2021). While the merit of producing carbon credits remains challenged as focusing on a downstream solution, the production of carbon in society will continue to be endemic, and carbon removal will need to continue for the foreseeable future. The IPCC Mitigation report includes the point that carbon dioxide removal will be needed to counter-balance residual emissions (Shukla et al. 2022, SMP-36) in the energy sector during the transition to a sustainable energy system.

Carbon removal practices such as reforestation, improved forest management, soil carbon sequestration, peatland restoration, and blue carbon management are examples of methods that can enhance biodiversity and ecosystem functions, employment, and local livelihoods (Shukla et al. 2022, SMP-48). These nature-based solutions provide adaptation and mitigation benefits for climate change as well as contributing to other sustainable development goals (Pörtner et al. 2022, 2-137) which are enabled through financing and accessibility by the blockchain trading system as identified in results sections 4.3.2 and 4.3.1.

While the current blockchain system relies on energy which inherently comes with the problems associated with the fossil fuel reliant energy system, it has the potential to become a leverage point for accelerating carbon removal as well as energy systems change through financing renewable energy projects. We see that blockchain has the potential to support the ease of sale of carbon credits from projects which support ecosystem health and promote nature-based solutions, thereby supporting the sustainability of the socio-ecological system.

5.4 Post Research Reflection

Looking back at our methods and process we find aspects of the study which could have yielded better results and insights. The following are insights on what we may do differently if given the chance to repeat the study:

1. The responses from our written survey were not robust, perhaps because of the timing or the format of data collection. The objective of the survey was to compliment social and ecological sustainability findings of our study. We believe we could have gotten more data from the survey to compliment the interview data and have a more holistic view of the

ecological and social sustainability of the organizations in the study if we had designed these questions into the interview session.

2. In line with the above point, if we were to design the sustainability aspects (in the context of the SPs) of the data collection, we could have limited our study to just the primary research question. Because we had three more secondary questions, we spent time during the interview probing for data in all these aspects. Had we focused on just the primary question, we would have been more focused and gotten detailed data on the primary research question as well as probed the sustainability aspects during the interview. This would have ultimately added value to our findings and enriched our insight.
3. We could have included in our respondents/case studies traditional brokers of carbon credits that do not use blockchain. By doing so, we would have a reference for comparison on the roles of marketplaces within the voluntary carbon market.

5.5 Recommendations

Blockchain technology has the potential to scale the voluntary carbon market in a sustainable way if, beyond transparency on-chain, disclosure policies are established off-chain and the market players are in consonance on the definition of quality. Weak governance systems off-chain coupled with the anonymity and openness of the blockchain system portends a danger for the carbon market to be filled by bad players who are out to trade solely to take advantage of the players in the system for financial benefits with little or no concern for climate change. A market failure could result from the influx of many of such bad players.

Establishing disclosure policies/KYC for buyers, pre-market entry, is a good way to increase fairness in Decentralized Autonomous Organizations (DAOs) and is a starting point in creating a structure for some level of regulation around the market. This would also have an additional benefit of generating insights on buyers and sellers, e.g., consumption patterns or general lifestyle (for individuals) and transparency in corporate need for offsetting. As activities on and off-chain are accounted for, comparison and analyses of both datasets will inspire the development of smart contracts that will hedge against unethical behaviors within the blockchain system.

Because of the conflict of interest that presents itself with carbon credit marketplaces consulting on carbon accounting for purchasers, there is an opportunity for third-party carbon accounting organizations to offer carbon accounting advisory services. As carbon emission reduction is a first step towards net-zero, carbon accounting is invaluable in helping organizations be aware of their process and energy flows which would help them to purchasing carbon credits in the most economical way.

From our studies, additionality, permanence, and co-benefits are the most referenced qualities that define a quality carbon credit. These qualities can serve as baseline quality metrics for the voluntary carbon market to establish a reference price for carbon credits. Because not all blockchain entities accept carbon credits that have been validated by other entities besides the legacy carbon registries, more standardized verification schemes need to be supported to promote inclusion. Innovations for IoT-enabled, end-to-end self-verification of carbon on blockchain should be promoted to encourage proliferation of carbon projects. Also, new carbon verification schemes should disclose their verification methodologies for peer-review, to guarantee the quality of carbon credits.

Criticisms or the ignorance about the use of the blockchain technology can be partly addressed by educating the public about the technology and its use. Generally, stakeholders in the blockchain- voluntary carbon markets- space need to be educated on four domains (blockchain, Web3, carbon markets, carbon project industry). Online materials or webinars for instance can help inform the public on Web3 and the value of purchasing carbon credits as transitioning agents towards a sustainable future.

Shared values on moving towards the sustainability is a substance to build strategic linkages between blockchain entities, project developers, and the legacy carbon registries. Partnerships between blockchain entities and project developers can be strategically forged to support projects with co-benefits while increasing the growth of carbon projects. Creating a high-level project checklist document to assess the project methodologies, carbon verification, as well as other indices for assessing co-benefits is a starting point to assess interest in partnership or collaboration. Partnerships between blockchain entities and legacy carbon registries will help in increasing their credibility in the carbon market, to create confidence in the market to source carbon credits on chain.

As technology is a fast-changing industry, building innovative solutions in the blockchain-VCM space should take into consideration designing solutions that create a flexible platform for building other solutions that will help to support society's transition towards sustainability. This would help to achieve the scale needed for meeting short term and long-term commitments of stakeholders towards reaching net-zero.

Recommendations for further research include research on the nuances of what a quality carbon credit entails and the acceptable definition for pricing in carbon markets. Further research could dive deeper into each of the secondary research questions presented in this thesis as primary research questions on their own. We have revised the conceptual framework to include aspects we consider useful for similar research in the future—see Appendix A6 Revised Conceptual Framework.

6 Conclusion

In attempting to solve the problems innate with carbon trading in the voluntary carbon market, blockchain technology was introduced as a promising solution. This thesis sought to identify the roles of blockchain in carbon trading in the voluntary carbon market through a sustainability lens by interviewing and surveying seven organizations involved in the nexus of blockchain and carbon credit trading.

For our primary inquiry, we observed that blockchain could enable the VCM by aiding scaling, liquidation and driving up the price of carbon credits. The high price of carbon credits could create awareness on the economics of purchasing carbon offsetting versus reducing internal emission. But the sustainability of this benefit is currently challenged by inadequate governance systems off-chain, market consonance on the definition of quality credits, validation of carbon verification methodologies fragmented in the market, and inadequate or lack of education on the use and potential value of blockchain technology.

Blockchain provides a platform upon which innovation in environmental technology could thrive. By being involved in the transitional system that carbon trading offers in the energy transition pathway, blockchain is a potential tool to catalyse change for decarbonization and be a tool that brings forth the emerging sustainable future as illustrated by the 3 Horizons Framework. Although the carbon-blockchain niche has been able to keep its resource demand lean by adopting PoS validation and remote work, the overarching global technology that it is built on does not share the same attribute. It is important to note that the application of blockchain for carbon credits inherits the SP violations of the global energy and technology system. Also, there is a need to strengthen partnership and collaboration between players to unify technologies and help attain a common socioecological objective.

With respect to our secondary research questions, we observe that tokenizing carbon credits makes it possible for developers to hold digital certificates of their carbon credit that is liquid, potentially incentivizing project developers to develop more carbon projects. Blockchain technology has the potential to strengthen buyers' commitment to Net-Zero as it makes offsetting accessible to individuals and organizations that are committed to environmental goals. Our research findings do not reveal any direct link blockchain and increased quality of carbon credits, but our hypothesis is that blockchain has the potential to help buyers determine what credit type to purchase that suits their needs, subject to buyers' understanding of the meaning of a quality carbon credit. Public education on blockchain, carbon market, and/or carbon project industry domains could help the market reach a consensus on what a quality credit is for a reference carbon price determination. The disintermediation of the carbon market by the use of blockchain technology potentially contributes to project developers having fair financial remuneration for their work, subject to governance considerations off-chain.

To conclude, the application of blockchain with carbon credits has the potential to contribute to socio-ecological sustainability by enabling scale and access to carbon removal or avoidance. Although the solutions provided by the carbon credit market focus on solving symptoms of problems instead of addressing inherited problems, when applying a system perspective, the authors see the application of blockchain to the carbon market has potential to assist society's transition towards a sustainable future.

References

Allen, Myels, Kaya Axelsson, Ben Caldecott, Thomas Hale, Cameron Hepburn, Conor Hickey, Eli Mitchell-Larson, Yadvinder Malhi, Friederike Otto, Nathalie Seddon, Steve Smith. 2020. “The Oxford Principles for Net Zero Aligned Carbon Offsetting.” https://www.smithschool.ox.ac.uk/publications/reports/Oxford-Offsetting-Principles-2020.pdf"

Ashley, J. Michael, and Mark S. Johnson. 2018. “Establishing a Secure, Transparent, and Autonomous Blockchain of Custody for Renewable Energy Credits and carbon Credits.” *IEEE Engineering Management Review* 46, no. 4, (Fourth Quarter, December). https://ieeexplore.ieee.org/document/8486626.

Aspers, P., and Corte, U. 2019. “What is Qualitative in Qualitative Research?”. *Qualitative Sociology*, 42(2), 139–160. https://doi.org/10.1007/s11133-019-9413-7"

Blaufelder, Christopher, Cindy Levy, Peter Mannion, and Dickon Pinner 2021. “A Blueprint for Scaling Voluntary Carbon Markets to Meet the Climate Challenge.” McKinsey Sustainability. https://www.mckinsey.com/business-functions/sustainability/our-insights/a-blueprint-for-scaling-voluntary-carbon-markets-to-meet-the-climate-challenge."

Broman, Göran, and Karl-Henrik Robèrt. 2017. “A framework for strategic sustainable development.” *Journal of Cleaner Production* 140: 17–31. http://doi.org/10.1016/j.jclepro.2015.10.121.”

Brundtland, Gro Harlem. 1987. “Report of the World Commision on Environment and Development: Our Common Future”, UN

Chen, Delton. 2018. “Utility of Blockchain for Climate Mitigation.” The Journal of the British Blockchain Association 1, no. 1: 1–9. https://doi.org/10.31585/jbba-1-1-(6)2018"

Cohen-Shacham, E. et al. 2019. “Core principles for successfully implementing and upscaling Nature-based Solutions.” *Environmental Science & Policy*, 98, 20-29, doi:10.1016/j.envsci.2019.04.014."

Crémer, Jacques, Gregory S. Crawford, David Dinielli, Amelia Fletcher, Paul Heidhues, Monika Schnitzer, Fiona M. Scott Morton, and Katja Seim. 2021. “Fairness and Contestability in the Digital Markets Act.” SSRN. The Tobin Center for Economic Policy, Accessed May 25, 2022. http://dx.doi.org/10.2139/ssrn.3923599"

Crutzen, Paul J. 2006. “The Anthropocene”. In Earth System Science in the Anthropocene, edited by Dr. Eckart Ehlers and Dr. Thomas Krafft, 13-18. Berlin and Heidelberg: Springer. http://doi.org/10.1007/3-540-26590-2_3.

Dimitri, N. 2021. “Monetary Dynamics with Proof of Stake.” Frontiers in Blockchain, 4. DOI=10.3389/fbloc.2021.443966

Ecosytem Marketplace & Business for Social Responsibility 2008. “Offsetting Emissions: A Business Breif on the Voluntary Carbon Market.” Second Edition. https://www.bsr.org/reports/BSR_Voluntary-Carbon-Offsets-2.pdf

Ethereum. 2022. Accessed May 13, 2022. https://ethereum.org/en/layer-2/

Gallersdörfer, Ulrich, Lena Klaaßen, Christian Stoll. 2022. “Energy Efficiency and Carbon Footprint of Proof of Stake Blockchain Protocols.” Crypto Carbon Ratings Institute.

Howson, Peter, Sarah Oakes, Zachary Baynham-Herd, Jon Swords. 2019. “Cryptocarbon: The promises and pitfalls of forest protection on a blockchain.” *Geoforum* 100, no. 1: 1-9. https://doi.org/10.1016/j.geoforum.2019.02.011

Iansiti, Marco, Karim R. Lakhani. 2017. “The Truth About Blockchain.” Harvard Business Review, January–February 2017. https://hbr.org/2017/01/the-truth-about-blockchain

International Carbon Reduction and Offset Alliance. 2021. Accessed May 10, 2022. “ICROA CODE OF BEST PRACTICE.” https://www.icroa.org/code

International Carbon Reduction and Offset Alliance 2020. “Evolution of Voluntary Carbon Market (VCM).” https://voluntarycarbonmarket.org/

Kapnick Sarah 2021. “The Global Carbon Market: How Offsets, Regulations and New Standards May Catalyze Lower Emissions and Create Opportunities.” J.P. Morgan Asset Management. https://am.jpmorgan.com/content/dam/jpm-am-aem/global/en/insights/portfolio-insights/JPM53391the-global-carbon-market.pdf

KlimaDAO. 2022. Accessed May 18, 2022. ttps://www.klimadao.finance/blog/polygon-pos-emissions-analysis

Kreibich, Nicolas, and Lukas Hermwille. 2021. “Caught in Between: Credibility and Feasibility of the Voluntary Carbon Market Post-2020.” *Climate Policy*, vol. 21, no. 7, 939–957. 10.1080/14693062.2021.1948384.

Leonhard, Robert. 2017. “Forget Paris: Building a Carbon Market in the US Using Blockchain-Based Smart Contracts.” SSRN 3082450. http://dx.doi.org/10.2139/ssrn.3082450

Nori. 2022. Accessed May 13 2022. https://nori.com/credible-carbon-removal

Pörtner, H.-O. , D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.). 2022. “IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.” Cambridge University Press. In Press.

Robèrt, Karl-Henrik, Göran Broman, David Waldron, Henrik Ny, Sophie Hallstedt, David Cook, Lena Johansson, Elaine Daly, Jonas Oldmark, George Basile, Hördur Haraldsson, Jamie MacDonald, Brendan Moore, Tamara Connell, Merlina Missimer, and Pierre Johnson. 2019. Sustainability Handbook, 2nd ed. Lund: Studentlitteratur.

Rosales Raúl, Priya Bellino, Marwa Elnahass, Harald Heubaum, Philip Lim, Paul Lemaistre, Kelly Siman, and Sofie Sjögersten. 2021. “Voluntary Carbon Markets in ASEAN: Challenges and Opportunities for Scaling Up.” https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1026880/Green_Finance_COP26_Universities_Network_Policy_Report.pdf.

Science Based Targets Initiative. 2022. “SBTI Corporate Net-Zero Standard”. Accessed 13 May 2022. https://sciencebasedtargets.org/resources/files/Net-Zero-Standard.pdf

Sharpe, Bill, Anthony Hodgson, Graham Leicester, Andrew Lyon, and Ioan Fazey. “Three Horizons: A Pathways Practice for Transformation.” *Ecology and Society* 21, no. 2 (2016). http://www.jstor.org/stable/26270405.

Shukla, P.R., J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley. 2022. “IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.” Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926

Taskforce on Scaling Voluntary Carbon Markets. 2021. “Taskforce on Scaling Voluntary Carbon Markets Final Report.” January 2021.

Thedéen, Erik and Björn Risinger. 2021. “Crypto-assets are a threat to the climate transition – energy-intensive mining should be banned.” Finanspektionen, November 2021. https://www.fi.se/en/published/presentations/2021/crypto-assets-are-a-threat-to-the-climate-transition--energy-intensive-mining-should-be-banned/

UNFCCC. n.d. “Emissions Trading.” Accessed February 14, 2022. https://unfccc.int/process/the-kyoto-protocol/mechanisms/emissions-trading”

Zhao, Fangyuan, and Wai K. Chan. 2020. “When Is Blockchain Worth It? A Case Study of Carbon Trading.” *Energies 13*, no. 8: 1980. https://doi.org/10.3390/en13081980

Appendices

A1 Interview Questions

Social

1. Who gets value from this application? (Farmers, foresters)
    a. *Who do you prioritize ROI for the most - investors, suppliers?*
2. Do you think purchasing carbon credits affects voluntary buyers' emissions habits? i.e., if the buyers believe purchasing offsets mitigates their emissions, do they emit more?
3. Does your organization strive for any internal environmental goals (net zero by 2030 etc)?
    a. *Do you have a system for measuring your own carbon footprint?*
4. Can you share a story with us about how your organization responded to criticisms that blockchain is not environmentally friendly?

Environmental

5. What measures, if any, are taken for accountability of ensuring the carbon stays sequestered?
6. Is carbon credit **verification** made more accessible through your platform? If so, how?
7. How does the application of blockchain and carbon credits affect the development of carbon offset projects?
    a. *supply of carbon credits to be sold?*
    b. *opportunities for carbon credit supply?*

Economic

8. Where do the blockchain based carbon traders see themselves in 10 years or more?
    a. Does this system assume or require infinite growth in carbon sequestration projects to maintain the business side?
    b. What's your business case model for investors?

Governance

9. Do you have disclosure policies for your (or your clients') current emissions, accounting practices, targets to reach net zero, or the type of offsets you employ?
    a. *If yes, what are they - and are there measures to verify, to any degree of confidence, claims in the disclosures made by your clients?*
    b. *If no, is it something you think is worth considering - and why (or why not)?*
10. What criteria is used by your organization to select verification bodies for verifying carbon credits? Why?

Tech and Innovation

11. How does blockchain help accelerate the transition to a low carbon future?
    a. *(Short, medium, long-term goals i.e., net zero by 2030, 2050, beyond) How does it fit into the urgency of climate change?*
12. What are the main barriers to adoption of your business model/ innovation?

13. How does your technology aid ease and convenience of purchasing carbon credits?
14. What technologies do you use? (Blockchain network, smart contract, language etc.)?
    a. *What are its pros and cons with respect to the alternative technologies?*
15. How far into the future could the security of the platform be guaranteed?

A2 Survey Questions

1. How gender balanced was your organizations design team?
2. Do you have any policies for diversity within your organization?
3. Does your organization have an exponentially increasing demand for data storage?
4. Do you see this as something that will happen in the future?
5. If yes, how does your organization intend to manage this?
6. Does your organization have an exponentially increasing demand for energy?
7. Do you see this as something that will happen in the future?
8. If yes, how does your organization intend to manage this?
9. What type of hardware does your organization use?
10. How old is the hardware?
11. How soon will it need to be replaced?
12. How does old hardware get disposed of?
13. Does your organization utilize server farms?
14. Does your organization own the server farm or is it owned by a third party?
15. Where is the sever farm located?

A3 Coding Guide

Code	Topic	Sub Topic	Notes
A1	Accountability	Bright spots of blockchain	Accountability as in efficiencies of the blockchain with carbon credits system
A2	Accountability	Transparency	
A3	Accountability	Trust	
A4	Accountability	Double counting	
A5	Accountability	Scalability	
C1	Carbon credits	Types	Regenerative farming, REDD+, etc
C2	Carbon credits	Verification bodies, monitoring	From third parties (VERRA etc) or organization itself
C3	Carbon credits	Quality credits	Some orgs give their own definition of 'quality credits' some use the ICROA standards as the definition
C3a	Carbon credits	Co-benefits	Some orgs define quality credits as having more co-benefits, others bring co-benefits up outside the quality credits discussion
C3b	Carbon credits	Real*	ICROA standards
C3c	Carbon credits	Measureable	ICROA standards
C3d	Carbon credits	Permanence* (accountability of storage)	ICROA standards, including insurances
C3e	Carbon credits	Additional*	ICROA standards
C3f	Carbon credits	Independently verified	ICROA standards
C3g	Carbon credits	Unique	ICROA standards
C5	Carbon credits	Transferability	Using credits for things besides retirement
D1	Deficencies	Of old syestem	
D2	Deficencies	Of new system	Anything that we might be able to poinpoint as room for improvement
E1	Environmental	Benefits	Benefits for the environment of using this application
E2a	Environmental	Emissions of buyers	CO2 calculator
E2b	Environmental	Emissions of blockchain	
E3	Environmental	Energy	
E4	Environmental	Urgency of problem	
F	Future		
I1	Infrastructure/Technology	Blockchain, NFTs	Types (ethereum, polygon, etc)
I2	Infrastructure/Technology	Contracts	
I3	Infrastructure/Technology	Usability	User experience
I4	Infrastructure/Technology	Barriers to adoption	
I5	Infrastructure/Technology	Security	Of encyrption/technology
M1	Markets	Financing	Investment, ROI, revenue
M2	Markets	Tradability	Tokenomics
M3	Markets	Supply/Demand dynamics	Scalability, liquidity
M4	Markets	Price of Carbon	

A3 Coding Guide

Code	Topic	Sub Topic	Notes
O1	Organization specific	Structure	How they issue credits, blockchain used, or other unique points
O2a	Organization specific	Policy - environmental and emissions	Internal emissions, calculations, and goals
O2b	Organization specific	Policy - KYC	
P	Policy	Government	
S1	Social	Benefits	Social good, accessibility
S1a	Social	Benefits, supply specific	
S1b	Social	Benefits, buyer specific	
S2	Social	Education	
S3	Social	Rebound effect	
S4	Social	Societal license	Trust
S5	Social	Partnership	
XX	OUTLIERS	anything that doesn’t fit in the categories yet	

A4 Quality Credits

Organization	Response when asked what defines a 'quality credit'
Organization 1	Believes it is comparing apples to oranges trying to valuate one project over in determining a definition for a high-quality credit.
Organization 2	Definition when asked about what a high-quality credit entails gave the short answer of "nature-based solutions." Expanding on that, they go on to say "I view it more as a spectrum where like, there's a sort of baseline of quality, where you need to be verified by a reputable standards body like Verra, under an accepted methodology that has additionality and all the other important characteristics that define a proper carbon offset that sort of like a baseline… beyond that, I think there's a clear pressure in the market to focus on nature-based solutions to focus on drawdown rather than just mitigation… any verified offset is a good offset like as long as it is verified under a accepted methodology that has additionality." They also speak to the issue of scale, that an increase in both quality and volume are going to be required for the voluntary carbon market to have meaningful impact on the climate issue. They also note that the incentive to produce higher quality credits will increase due to profit margins going up for higher priced credits, but that if the market limits itself to the consumption of just the high-end solutions, the scale is not there yet, and that there also needs to be a pricing spectrum for buyers of different financial situations. They go on to mention the nuance of calling something a 'quality credit' when comparing credits attached to a renewable energy project versus a reforestation project. The renewable project may have more permanence assured to it, but the nature-based solution has more co-benefits.
Organization 3	Believes a high-quality credit has third party verification to avoid conflicts of interest, which also have methodologies that have been developed in a transparent way. They go on to mention Gold Standard and Verra in response to quality. They conclude by saying "But I don't differentiate, between the quality of, you know, say mitigation offset or removal offset. I think they both have value. I think projects that have co-benefits in terms of community development, economic empowerment, if they touch on social issues, like, you know, then I guess you can say those are higher quality, but it depends, like, is your quality standard based on the overall impact to the offset, or is your quality standard based on the environmental benefit? Because those can be different things."
Organization 4	Sets their own standard of what a high-quality credit is. They also believe there are co-benefits to why regenerative agriculture is beneficial besides carbon: "there's other ecosystem benefits, aside from just removing carbon, that might be more interesting to the farmer and might in the long run, pay them more, like soil and nutrient retention and preventing erosion and leaching into groundwater… there's a lot of different ecosystem benefits besides carbon."
Organization 5	Aspires to create a "holistic credit which creates a balanced series of co-benefits and are valued for ecosystem services." Projects this organization is working on are described as carbon being the focal point but having a lot of ecosystem services as co-benefits, which bring extra value to establish a high-quality credit. This organization addresses high-quality credits to increased complexity and thinks it's better to look at the project in a holistic way, instead of becoming too fixated on the carbon numbers, because comparing values of different impact categories is difficult to measure.

A4 Quality Credits

Organization	Response when asked what defines a 'quality credit'
Organization 6	Relayed that it is up to the person who purchases the credit and what is valid for them and therefore believes there is disagreement around what a quality credit entails. They go on to say additionality is the baseline, and that the differentiation revolves around permanence and co-benefits. They claim that a project with more permanence compared to another in the face of the urgency of the climate issue does not give it more quality, but simply more permanence, but the value of the permanence differentiates on the open market. With regards to co-benefits, they explain that because co-benefits are hard to quantify as an exact price, it's easier to say they are better quality. The credit still has a tonne removed, but there are co-benefits that are unable to be priced. In summary they conclude: "I think people who spend their time nitpicking it, lose sight of the bigger picture, which is you need all these solutions... Stuff that people deem higher quality, they pay more for… value is in the eyes of the beholder… It's a tricky, tricky word to use. And I try to shy away from it because it's just, there's a lot of context that's missing and that most people don't have the background to understand."
Organization 7	Thinks a high-quality credit or project is one that is highly additional. They also highlight permanence in reference to permanent land use switching. Quoting: "where you're using that credit revenue, to create some kind of alternative form of revenue, whether that's through agroforestry, or another activity that's productive in a much more sustainable way," as something they look for when selecting projects to offer.

A5 Organization Specific Features

	Creol	Flowcarbon	KlimaDAO	Nori
Blockchain Network	Polygon	Plans to launch on Polygon	Polygon	Polygon
Associated Location	United Kingdom main operation, decentralized staff, supports credits produced globally.	United States main operation, decentralized staff, supports credits produced globally.	Global operation, decentralized staff, and global project locations.	Only operates and produces credits from the United States. Purchases of credits may be made globally. Decentralized staff.
Type of Project Supplied	Forest protection, wind energy, and solar projects.	Only nature-based methodologies accepted such as conservation, reforestation, nature restoration.	Multiple project types through bridging existing carbon credits and bonding of other organizations credits being brought into KlimaDAO's treasury in exchange for KLIMA. Some other organizations able to bond are Toucan, MOSS, and C3.	Regenerative agriculture projects.
Token or Service	Offers one off purchases or subscriptions of certified carbon credits. Unable at this time to select from which project purchased credits come from. Also offers a wireless IoT building control systems which measures and controls building energy efficiency and can automatically offset the remaining impact.	Goddess Nature Token (GNT), GCO2; nature-based carbon offset credits that have a vintage no older than 5 years backed by a market-recognized carbon registry.	Fungible KLIMA tokens backed by at least 1 Verified Carbon Unit in the KlimaDAO treasury, which gives its holders the ability to vote on KlimaDAO policy.	NORI token, tradable for Nori Carbon Removal Tonnes or “NRTs”.

A5 Organization Specific Features

	Creol	Flowcarbon	KlimaDAO	Nori
Verification of carbon credit	Verra, Gold Standard	Verra	Verra and others associated with bonding.	Verification where farmers commit to enter data every year for 10 years using a modelling program and an independent third party estimates carbon removal.
Purchase of carbon credit	One-off purchases or subscriptions; payable through website.	A customer buys tokens on flowcarbon.com. After purchase, Flow Carbon sends the tokens to the purchaser's wallet. Or, a customer swaps ETH, MATIC or other ERC-20 tokens for the GCO2 token on a DeFi exchange. GCO2 can be swapped for GNT to be retired, or GCO2 can be retired directly.	Buyers can use a credit card to purchase KLIMA tokens directly to a digital wallet; on a Polygon wallet with MATIC, buyers can use decentralized exchanges to swap for KLIMA; or bonding - the process of depositing carbon assets in exchange for discounted KLIMA.	Carbon credit purchases can be made on the organizations website by credit card and a digital certificate in the form of an non-transferrable NFT is issued. NORI token is yet to be launched. To buy Nori tokens a digital wallet will be needed.
Unique Points and Collaborations	Wireless IoT building control systems which measure and control building energy efficiency and can automatically offset the remaining impact.	Offers a two-way bridge enabling GNT tokens to be retired (claimed as carbon offset), unwrapped (turned back from fungible GNT token back into the GCO2 which represents the carbon credit), or redeemed (unwrapped and traded in for the underlying off-chain unretired carbon credit) as they move on and off chain. Has collaborated with Celo, a recently launched blockchain project, to develop open on-chain market infrastructure.	A decentralized autonomous organization creates a treasury backed by real world assets (carbon credits), brings together different types of carbon credits through bonding to increase value of KLIMA and encourage market mechanics of tokenizing credits. Uses Toucan Bridge and bonding to migrate carbon credits on-chain.	Defers from ICROA standards in regards to permanence and additionality. Nori uses a 10 year assurance of permanence, compared to the usual 100. They do this stating that the urgency of climate change will happen in the next few decades, and longer permanence is not as much needed right now as more solutions are needed. Additionality is defined by Nori as incremental and measurable changes in carbon removal year over year, instead of the ICROA definition which states that additionality must be in a project that would not have occurred without financial support from the market or registry.

A5 Organization Specific Features

	Offsetra	ONCRA	Toucan
Blockchain Network	Polygon	Potentially launching on Cardano	Polygon
Associated Location	United Kingdom main operation, decentralized staff, supports credits produced globally.	Netherlands main operation, decentralized staff, unclear where projects are sourced.	Switzerland main operation, decentralized staff, supports credits produced globally.
Type of Project Supplied	Forest conservation projects, wind energy in India.	Various nature-based solutions.	Various projects available from established registries.
Token or Service	Offsetra Grow - A monthly subscription based program which retires offsets pre-purchased by Offsetra. Bulk purchasing services are provided outside of the above program when purchasing 5,000 tonnes or more.	Currently available on invitation only.	Toucan Bridge - The Toucan Bridge connects the voluntary carbon market to Web3 and can be connected to any source of offsets. For each credit bridged, one Tokenized CO2 (TCO2) token is deposited. TCO2s are semi-fungible, retain valuable metadata, and can be pooled for max liquidity. Base Carbon Tonne (BCT) - First Carbon Pool designed with Klima DAO, where tokenized carbon credits (called TCO2 tokens) can be deposited in once bridged. Nature Carbon Pool (NCT) - represents carbon tokens from nature-based projects, and is the first open, pooled, nature-based token. Toucan Meta-Registry - Carbon credits bridged into TCO2s share standardized data, regardless of the source registry. This breaks down market silos while improving accessibility and transparency.

A5 Organization Specific Features

	Offsetra	ONCRA	Toucan
Verification of carbon credit	Verra, Gold Standard	Protocols are designed on a project basis with methodologies that can be peer reviewed and scientifically accepted to get metrics to build on.	Verra, soon to add Gold Standard and others.
Purchase of carbon credit	One-off purchases or subscriptions; payable through website.	Currently available on invitation only.	TCO2 is created when carbon credits are bridged. To buy BCTs is by buying it directly from decentralized exchanges such as SushiSwap on Polygon.
Unique Points and Collaborations	Buyers have easy access to offsetting without needing much knowledge of blockchain or the deFi space. Uses Toucan Bridge to migrate carbon credits on-chain.	ONCRA stands for Open Natural Carbon Removal Accounting developed as an open accounting standard and transaction rulebook for natural climate solutions. Attracts entrepreneurs who are working with climate solutions with nature-based techniques to create verified carbon credits. Utilizes digital solutions such as satellite imaging to account for carbon credits.	The Toucan Carbon Bridge allows anybody to bring their carbon offsets on-chain in a tokenized form. Toucan Carbon Pools are reference pools with a corresponding carbon reference token meant to group similar projects to generate a sense of similar quality projects.

A6 Revised Conceptual Framework

1. Social
   - Human need or what the solution helps to fulfil in society.
   - Inspiration for society (e.g., via communications of adopted principles to the public).
   - Societal license to operate (e.g., trust from the public).
   - Incentivization for project developers.
   - Public education in
     - Blockchain
     - Carbon market
     - Industry of project development
     - Specific project development methods or considerations
     - Sustainability challenge
   - Partnership for co-benefits
   - Equality of opportunities

2. Environmental
   - Environmental integrity
   - Support the restoration and protection of a wide range of natural and semi-natural ecosystems in their own right.
   - Support the prevention of the re-release of stored carbon.
   - Carbon footprint (of blockchain system & clients)

3. Economic
   - Market maturation
     - Catalyze structured finance (e.g., using long-term agreements to give the certainty required by offset project developers to create net zero offsets).
     - Improved liquidity from standardized contracts.
     - Demand signaling.
     - Scale up high-integrity supply.
     - Carbon pricing mechanism
   - Return on Investment.
   - Economics of Carbon Offsetting

4. Governance
   - Systems and structures: Global anti-money-laundering (AML)/know-your-customer (KYC) guidelines, legal and accounting frameworks.
   - Third-party carbon accounting
     - Carbon credit integrity
     - Offset eligibility guidelines and principles for offset standards, suppliers, and validation and verification bodies.
     - Disclosure: (e.g., of current emissions, accounting practices, targets to reach net zero, and the type of offsets you employ).
     - Transparency.

5. Technology and Innovation
   - Advanced data infrastructure (e.g., to accelerate market maturation)

- Efficient and accelerated verification (to promote time as a critical factor in meeting climate sustainability goals).
- Ease of carbon credit trading.
- Technology platform is flexible for (re)creating designs/platforms that can help organizations reach net zero.

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