

Applying blockchain for climate action in agriculture: state of play and outlook

Background paper



Applying blockchain to climate action in agriculture: state of play and outlook

Background paper

Lan van Wassenaer, Mireille van Hilten and Marcel van Asseldonk Wageningen University & Research And Erik van Ingen Food and Agriculture Organization of the United Nations

> Published by the Food and Agriculture Organization of the United Nations and Wageningen University & Research

Rome/Wageningen, 2021

Required citation:

Van Wassenaer, L., van Hilten, M., van Ingen, E., van Asseldonk, M., 2021. *Applying blockchain for climate action in agriculture: state of play and outlook*. Rome/Wageningen, FAO and WUR. https://doi.org/10.4060/cb3495en

The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations (FAO) or Wageningen University and Research (WUR) concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The mention of specific companies or products of manufacturers, whether or not these have been patented, does not imply that these have been endorsed or recommended by FAO or WUR in preference to others of a similar nature that are not mentioned.

The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO or WUR.

ISBN 978-92-5-133920-6 [FAO] ISBN 978-94-6395-588-1 [WUR] © FAO, 2021



Some rights reserved. This work is made available under the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 IGO licence (CC BY-NC-SA 3.0 IGO; https://creativecommons.org/licenses/by-nc-sa/3.0/igo/legalcode).

Under the terms of this licence, this work may be copied, redistributed and adapted for noncommercial purposes, provided that the work is appropriately cited. In any use of this work, there should be no suggestion that FAO endorses any specific organization, products or services. The use of the FAO logo is not permitted. If the work is adapted, then it must be licensed under the same or equivalent Creative Commons license. If a translation of this work is created, it must include the following disclaimer along with the required citation: "This translation was not created by the Food and Agriculture Organization of the United Nations (FAO). FAO is not responsible for the content or accuracy of this translation. The original English edition shall be the authoritative edition."

Disputes arising under the licence that cannot be settled amicably will be resolved by mediation and arbitration as described in Article 8 of the licence except as otherwise provided herein. The applicable mediation rules will be the mediation rules of the World Intellectual Property Organization http://www.wipo.int/amc/en/mediation/rules and any arbitration will be in accordance with the Arbitration Rules of the United Nations Commission on International Trade Law (UNCITRAL).

Third-party materials. Users wishing to reuse material from this work that is attributed to a third party, such as tables, figures or images, are responsible for determining whether permission is needed for that reuse and for obtaining permission from the copyright holder. The risk of claims resulting from infringement of any third-party-owned component in the work rests solely with the user.

Sales, rights and licensing. FAO information products are available on the FAO website (www.fao.org/publications) and can be purchased through publications-sales@fao.org. Requests for commercial use should be submitted via: www.fao.org/contact-us/licence-request. Queries regarding rights and licensing should be submitted to: copyright@fao.org.

Contents

	Fore	word	vii
	Ackr	nowledgements	viii
	Abb	reviations and acronyms	ix
	Exec	cutive summary	x
1	Intro	oduction	1
	1.1	Background	1
	1.2	Structure of this background paper	1
2	Rese	earch approach	2
	2.1	Objective	2
	2.2	Research questions	2
	2.3	Methodology	2
3	Bloc	kchain for climate change adaptation and mitigation (CCAM) in	
	agri	culture: Findings from the literature	4
	3.1	Key aspects of blockchain application	4
		3.1.1 General development of blockchain application	4
		3.1.2 Key components and attributes of blockchain application	5
	3.2	Climate change adaption and mitigation in agriculture	11
		3.2.1 CCAM strategies in agriculture	11
		3.2.2 Opportunities and challenges in registering and governing CCAM in	10
	2.2	Agriculture	13
	5.5	3.3.1. Blockchain for climate change in general	14
		3.3.2 Blockchain applications in agriculture	14
		3.3.3 Blockchain for CCAM in agriculture	16
		3.3.4 Challenges in applying BCT to CCAM in agriculture	17
4	Bloc	kchain applications for CCAM in agriculture:	
	Find	ings from the use cases	18
	4.1	Application of blockchain for CCAM in agriculture	18
	4.2	Enabling environment and challenges for the use cases	19
	4.3	Use of blockchain features in the use cases	20
	4.4	Blockchain ecosystem and the role of the public sector	21
	4.5	Impact and benefits for the farmer	23
	4.6	Outlook for blockchain application for CCAM in agriculture	24
5	Cone	clusions and recommendations	26
	5.1	Key features of blockchain to track GHG emissions and offsets	26
	5.2	Main areas of applications of blockchain in agriculture	26
	5.3	Key opportunities and challenges in applying blockchain for CCAM	
		in agriculture	26
	5.4	Policy options	27
	5.5	The role of blockchain applications for CCAM in agriculture	28
		5.5.2 Standardization	28 29
		5.5.2 Canacity development	20 28
			20

References and websites		
Appendix 1	Long list of use cases	36
Appendix 2	Shortlisted use cases	37
Appendix 3	Main features of BCT and Checklist Blockchain	
	applicability and steps in blockchain application	55

Tables

Comparison of different types of blockchain	8
CCAM Options and topics in Agriculture	13
Overview of topics and applications in different blockchain use cases in agriculture	15
Overview of potential blockchain applications for CCAM in agriculture	17
Overview of use cases using blockchain for CCAM studied in detail	18
Enabling environment for CCAM studied in detail	19
Overview of blockchain features used in the use cases	21
Main features of the blockchain ecosystem in the use cases	22
Overview of business benefits and climate impact of the use cases	23
A list of consensus mechanisms	55
A list of most used blockchain frameworks in blockchain applications	56
Actors in a blockchain ecosystem	57
	Comparison of different types of blockchain CCAM Options and topics in Agriculture Overview of topics and applications in different blockchain use cases in agriculture Overview of potential blockchain applications for CCAM in agriculture Overview of use cases using blockchain for CCAM studied in detail Enabling environment for CCAM studied in detail Overview of blockchain features used in the use cases Main features of the blockchain ecosystem in the use cases Overview of business benefits and climate impact of the use cases A list of consensus mechanisms A list of most used blockchain frameworks in blockchain applications Actors in a blockchain ecosystem

Figures

The (expected) hype cycle of blockchain in agri-food	4
Key components of blockchain application (high-level architecture) Based on ITU	
Reference Architecture (ITU-T, 2019)	5
Generic blockchain ecosystem, based on Riasanow et al. (2018)	9
Key actors in the blockchain ecosystem	10
Climate Change and CCAM activities Source: IPCC2001	12
Blockchain for Climate Change	16
Challenges of blockchain application in agriculture	17
	The (expected) hype cycle of blockchain in agri-food Key components of blockchain application (high-level architecture) Based on ITU Reference Architecture (ITU-T, 2019) Generic blockchain ecosystem, based on Riasanow et al. (2018) Key actors in the blockchain ecosystem Climate Change and CCAM activities Source: IPCC2001 Blockchain for Climate Change Challenges of blockchain application in agriculture

Foreword

Climate change represents one of the main threats to agricultural development, and poses unprecedented challenges to global food security, poverty eradication and sustainable development. There is no country exempted from the adverse impacts of climate change and its detrimental effects on agri-food systems are clearly visible everywhere in the world.

The urgency of meeting the goals of the 2030 Agenda for Sustainable Development and the Paris Agreement while responding to new challenges such as the ongoing Covid-19 pandemic requires a global transformation of the world's agri-food systems towards greater resilience and lower emissions. It is well recognised that this transformation will be possible only through enhanced innovation and strengthened collaboration across different sectors and actors.

In this context, the Food and Agriculture Organization (FAO) and Wageningen University & Research (WUR) share the belief that digital innovations are key to addressing global warming and strengthen climate resilience. Our institutions identified blockchain as an emerging technology that can be part of a new digital paradigm for climate action under the Paris Agreement. Blockchain is unique because of its libertarian roots and decentralised character, as embodied by its application in cryptocurrencies. However, we realise that this technology has a huge potential and we issued this research feeling the urge to reveal, investigate and understand the value and risks of possible applications of blockchain beyond its popular usage. With more and more people connected to the internet, new emerging technologies and an increasing awareness of producers and consumers towards carbon footprint, we believe that blockchain can indeed become part of a promising broad stack of digital innovation instruments that may be turned to support climate action in agriculture and agri-food systems.

FAO and WUR have a long-standing collaboration in the domain of food security, climate change adaptation and mitigation. We are confident that this publication provides an intellectual framework that helps the reader to make blockchain more tangible for climate action.

Eduardo Mansur Director Office of Climate Change, Biodiversity and Environment

Prof.dr.ir. J.G.A.J. (Jack) van der Vorst General Director Social Sciences Group (SSG) Wageningen University & Research

Acknowledgements

This study on *Application of blockchain in climate change adaptation and mitigation in agriculture: state of play and outlook* was carried out by Wageningen Economic Research and the Office of Climate Change, Biodiversity and Environment of the Food and Agriculture Organization of the United Nations (FAO). It was drafted by Lan van Wassenaer, Mireille van Hilten and Marcel van Asseldonk from Wageningen Economic Research in close collaboration with FAO by Erik van Ingen and under the overall management of Julia Wolf and Alessandro Spairani.

Review and contributions from FAO were provided by: Manar Abdelmagied, Natalia Alekseeva, Martial Bernoux, Dorota Buzon, Etienne Drieux, Shanali Pethiyagoda and Gerard Sylvester.

Thanks are owed to Rebecka Ramstedt (FAO) who coordinated the publication and dissemination of the paper, as well as to Zayd Abdulla (Wageningen University & Research) for editing.

Any omissions of contributors to this guide are unintentional. If you seek more information or would like to provide feedback, please contact: FAO-NAPs@fao.org or Lan.vanWassenaer@wur.nl.

List of abbreviations and acronyms

API	Application Programming Interface
ВСТ	Blockchain technology
BFT	Byzantine Fault Tolerance Algorithm
CA	Certificate Authority
CSA	Climate Smart Agriculture
CCAM	Climate Change Adaptation and Mitigation
DApp	Decentralized Application
dBFT	Delegated Byzantine Fault Tolerance
DDoS	Distributed Denial of Service
DES	Data Encryption Standard
DL	Distributed Ledger
DLT	Distributed Ledger Technology
DPoS	Delegated Proof of Stake
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse Gas
ICO	Initial Coin Offering
ICT	Information and Communication Technology
IM	Information Model
IoT	Internet of Things
IT	Information Technology
JVM	Java Virtual Machine
NbS	Naturebased Solutions
PDO	Protected Designation of Origin
PoC	Proof of Concept
PoS	Proof of Stake
POS	Point of Sale
PoW	Proof of Work
ROI	Return On Investment
SDG	Sustainable Development Goals
SDK	Software Development Kit
TTP	Trusted Third Party
UI	User Interface
VBFT	Byzantine Fault Tolerance with
WUR	Wageningen University & Research

Executive summary

Climate change adaptation and mitigation (CCAM) entails many challenges. Addressing these challenges requires transformational changes for which innovative solutions should be investigated. Among innovative digital technologies, the blockchain technology (BCT) has been considered to offer a unique opportunity to bring greater efficiency, transparency and traceability to the exchange of value and information in the agriculture sectors. To provide more background knowledge and insights into the promise and limitations of blockchain, this paper outlines the possible applications of BCT in agriculture and how it may be used in the context of climate change.

The objective of this study is to provide insights into potentialities, steps and best practices in applying BCT to use cases in agriculture in the context of climate change, to explore the opportunities and challenges in applying the blockchain technology in agricultural sectors with the aims of reducing greenhouse gas emission, increasing carbon sequestration, as well as supporting farmers' adaptation to climate change. Furthermore, this study also aims to shed light on policy options and propose policy guidance adapted to developing countries on blockchain applications.

Following the objective of the study, the following research questions were addressed:

- What are the key features of blockchain that will help in tracking GHG emissions and offsets?
- What are the main areas of application of blockchain in agriculture in the developing and developed worlds? What features of blockchain are relevant to climate change adaptation and mitigation in agriculture in developing and developed worlds?
- What are the key opportunities and challenges in applying blockchain in agriculture?
- What are the policy options that are relevant to the application of blockchain in agriculture?

The main methodology comprised of literature research and case studies based on information available on the internet. Nine use cases from different agriculture sectors in developing and developed countries were studied in detail and documented using a common template (see Appendix 2). Based on the findings from the literature and analysis of the use cases, this background paper describes the current state of play and outlook for applying blockchain to CCAM in agriculture.

Main features of blockchain application: distributed ledger, governance and ecosystem

BCT is not a single technology, nor is blockchain a single entity. At its core, blockchain is a distributed ledger that is consensually shared, replicated and synchronized among different nodes. Blockchain is also a governance technology for which rules and agreements need to be set and enforced with regard to the distributed ledger and the utilities derived from it. Blockchain application necessarily involves an ecosystem of different actors with different roles.

The implementation of BCT entails many technological choices and governance arrangements. This study provides an overview of the architectural components (see Figure 2) and technological choices to be made regarding the basic blockchain framework (see Table 10 and Table 11), the type of blockchains (see Table 1) and the roles of actors involved in the blockchain ecosystem (see Figure 3, Figure 4 and Table 12).



Figure E.1 Key components of blockchain application (high-level architecture) Based on ITU Reference Architecture (ITU-T, 2019)



Figure E.2 Generic blockchain ecosystem, based on Riasanow et al. (2018)



Internal stakeholders

Internal stakeholders Part of the blockchain project, having direct influence on the solution, such as an organization that initiated the blockchain project, a direct user, or a partner providing data. Any other partner or Information Technology (IT) organization working on the project as part of a value chain is an internal stakeholder as well.

Indirect stakeholders

The middle layer of indirect, optional stakeholders could in some projects be an indirect user, for example an organization that shares certification data on a blockchain.

External stakeholders

An external stakeholder is in the outer layer and does not influence the blockchain solution itself, but can be influenced by or influence blockchain solutions in general by for example contributing to blockchain regulations.

Figure E.3 Key actors in the blockchain ecosystem

Relevance of blockchain to climate change adaptation and mitigation (CCAM) in agriculture

The technical features of blockchain that will help in supporting climate adaptation strategies and tracking GHG emissions and offsets are: 1) decentralization and consensus mechanisms to ensure immutability of records; 2) smart contracts to ensure decentralized and automatic transactions; 3) redundancy and technical transparency to enable audit trail of permits, certification and transactions. When widely adopted, BCT enables and secures sharing of data and information on climate change and CCAM activities and building trust among people and organizations without resorting to a centralized system.

Opportunities and challenges of blockchain application for CCAM in agriculture

BCT can help improve transparency and accountability of CCAM activities and impacts in a wide range of verticals in agriculture (see Table 4). In supporting adaptation strategies, blockchain creates opportunities for new value chains and platforms for smallholder farmers through rural credits (through tokens), crowdfunding, crowd lending and microinsurance. Blockchain can also help in tracking the investments and outcomes of improved management practices for climate change adaptation. For climate change mitigation, the technology can lay the foundation for a global carbon data community that enables better monitoring and evaluation of climate change mitigation activities and supporting the development of carbon market. To support decision-making of public and social actors, blockchain can help track gender-relevant Sustainable Development Goal (SDG) indicators in CCAM activities in or related to agriculture.

In the current state of digitalization and standardization, however, many challenges need to be overcome before the potential governance and business benefits can be brought to fruition (see Figure 7). The common challenges faced by all use cases are the complexity of the technology and the scalability of the application in different business ecosystems. Many challenges are however situational and context specific. Capacity development (defined in this context as the process of unleashing, strengthening and maintaining the ability of people, organizations and society as a whole to understand and use blockchain effectively) and standardization are key to addressing the complexity of the technology. For the latter, substantial coordination efforts are needed to clearly define the use case and bring key stakeholders on board.

For initiators and operators of blockchain applications, the main challenge is how to acquire sufficient funding and technological resources for initial development and operations. Once the project is running, the major challenge is to attract additional funds and sufficiently large number of users for scaling up. For investors, the main challenge was the complexity and evolving nature of the technology which makes the success and return on investment uncertain. The complexity of the technology and its organization and the lack of empirical evidence on the ground constitute a major challenge for public actors, non-profit private actors or impact investors to commit themselves to or invest in blockchain projects. For regulators and public sector actors, the challenge is how to set the regulatory framework and safeguards without impeding innovation.

State of play and outlook for blockchain application for CCAM in agriculture

As evidenced by the rising number of use cases in both developing and developed countries, there is a high level of awareness of the relevance of BCT to CCAM in agriculture. The enabling environments of these usecases commonly feature favourable national and international policies towards CCAM in agriculture and digital economy. With its ease of deployment for decentralized applications (DApps) and token-based transactions, Ethereum is the most used blockchain framework in the use cases studied. Most use cases are currently funded by private companies or investors, with some through public private partnerships (PPP). Public sector actors such as governments and NGOs are playing supportive roles in financing the project and launching the application. Most of the use cases were initiated by technological start-ups.

In the use cases studied, different types of farmers are participating in blockchain applications. Smallholder farmers are generally the end users and beneficiaries (better access to finance and global value chains). Professional farmers are sometimes initiators, project partners and operators of blockchain applications. Users of blockchain-based credit or insurance in climate finance are mainly smallholder farmers, although traders, banks and insurance companies also benefit from increased sales and market volume.

BCT is still evolving. So are the blockchain applications for CCAM in agriculture. New blockchain frameworks and applications continue to emerge as the popularity of some existing applications began to wane. The outlook for the application of BCT for CCAM in agriculture depends on the following factors:

- regulatory framework regarding the governance of CCAM activities and the use of DLTs and cryptocurrencies;
- development of digital economies;
- development of the global carbon market (carbon credits, emission rights);
- transitions in the food system towards responsible consumption and social-ecological resilience;
- scalability and interoperability of different blockchains (development and adoption of social and technical standards regarding methodologies and data)

While it is difficult to predict what exactly will happen in the future, it is possible to anticipate and shape possible developments through a number of policy options.

Policy options

Based on the current state of play and outlook, three policy options are possible for governments and public institutions like FAO to guide and channel blockchain applications for CCAM in agriculture, especially in developing countries:

- establishing a regulatory framework regarding the choice of blockchain frameworks and governance models to ensure the alignment with SDGs and other objectives;
- coordinating and promoting standardization regarding the measurement and indicators of CCAM activities to be tracked by blockchain applications;
- awareness raising, training and capacity building, especially for smallholders in developing countries.

1 Introduction

1.1 Background

Climate change poses a severe threat to food security and other sustainable development goals as laid out in the 2030 Agenda for Sustainable Development. The Paris Agreement, adopted in 2015, aims to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels. The agreement also aims to strengthen the ability of countries to deal with the impacts of climate change, through appropriate financial flows, a new technology framework and an enhanced capacity development framework. Addressing these challenges requires transformational changes for which innovative solutions should be investigated. As concluded by the IPCC (2019), agriculture should be part of the solution.

In this global context, FAO actively investigates innovative technologies with potential to strengthen climate change adaptation action as well as identify the opportunities for channelling the mitigation potential in agriculture (see e.g., Trendov, Varas, and Zeng, 2019; Tripoli and Schmidhuber, 2018). One example is supporting the development of a strategic framework and guidelines on carbon footprint in agricultural value chains especially in countries that are partially or fundamentally reliant on agricultural production (see e.g., FAO, 2020a). Likewise, the development of strategies to mitigate greenhouse gas (GHG) emissions throughout value chains and promote adaptation to a changing climate is one of the key challenges towards contributing to a low carbon and resilient economy, including the provision to consumers of reliable information on the carbon footprint of agricultural products at the point of sale (POS) so that they can make better informed purchase decisions.

In these regards, digital innovations can have a significant impact on transforming the food system into more sustainable and transparent models that are resilient to the impacts of climate change. Among digital technologies, distributed ledger technologies (DLTs) have been considered to offer a unique opportunity to bring greater efficiency, transparency and traceability to the exchange of value and information in the agriculture sectors (including forestry, fishery) from production and processing to the market and final consumption. This is expected to bring consumers closer to farmers or agricultural producers. Among various versions of DLTs, blockchain is the most widely known and often identified as especially promising in addressing many problems in agriculture and the food system.

To provide more background knowledge and insights into the promises and limitations of blockchain, this paper outlines the possible applications of the blockchain technology (BCT) in agriculture and how it may be used in the context of climate change, while considering its comparative advantages, risks and limitations.

1.2 Structure of this background paper

This background paper is structured as follows: Chapter 2 presents the objective, key research questions, and the methodology of the study, following suggestions and recommendations from the FAO team. Chapter 3 contains a brief introduction to the key components and features of the blockchain technology and the conceptual framework whereby blockchain may contribute to climate change adaptation and mitigation (CCAM) in agriculture, based on review and study of existing literature. Chapter 4 summarizes the main findings from the use cases. Chapter 5 presents conclusions and suggests policy options that may be used by FAO to advance its work on agricultural innovations. Detailed information on the use cases and relevant background information are included in the Appendices.

2 Research approach

2.1 Objective

The objective of this study is three-fold:

- To provide insights into potentialities, steps and best practices in applying blockchain to use cases in agriculture in the context of climate change.
- To explore the opportunities and challenges in applying the blockchain technology in agricultural sectors with the aims of reducing greenhouse gas emission, increasing carbon sequestration, as well as supporting farmers' adaptation to climate change.
- To shed light on policy options and propose policy guidance adapted to developing countries on blockchain applications.

2.2 Research questions

Following the objective of the study, the following research questions were addressed:

- What are the key features of blockchain that will help in tracking GHG emissions and offsets?
- What are the main areas of application of blockchain in agriculture in the developing and developed worlds?
- What are the key opportunities and challenges in applying blockchain in agriculture?
- What features of blockchain are relevant to climate change adaptation and mitigation in agriculture in developing and developed worlds?
- What are the policy options that are relevant to the application of blockchain in agriculture?

2.3 Methodology

The main methodology was literature research and case studies based on literature and information sources available on the internet. To identify possible studies on the application of blockchain technologies in agriculture, we used the following Boolean combinations as search terms: 1) "blockchain" AND "climate change" AND "agriculture"; 2) "blockchain" AND "agriculture" AND "usecase"; 3) "blockchain" AND "agriculture" AND "case"; 4) "distributed ledger" AND "climate change" AND "agriculture". Furthermore, the 'snowball' method¹ was applied to locate relevant information. The text-mining software Leximancer² was used to identify main topics.

The main sources of desk study are:

- Academic and professional articles and reports available via Scopus (www.scopus.com) & Google Scholar (https://scholar.google.com/) as well as websites of FAO and the UN (https://www.un.org/en/sections/issues-depth/climate-change/index.html).
- Popular articles on the following tech websites: Wired (https://www.wired.com/), Medium (https://medium.com/topic/blockchain), 101 Blockchains (https://101blockchains.com/); Hackernoon (https://hackernoon.com/), TNW (https://thenextweb.com).
- Online databases on blockchain projects and applications such as the PositiveBlockchain (https://positiveblockchain.io/database-category/agriculture-food/).

¹ The snowball method is a way of finding literature by using a key document on the subject as a starting point and finding the publications which the author has consulted and any other publications that refer to this particular document.

² Leximancer 5.0 https://info.leximancer.com/products-academic

Based on the search through these sources, a long list of potential use cases were first compiled with their main features documented in Appendix 1. To select use cases for more in-depth study, we applied the following criteria:

- relevance to climate change & agriculture;
- addressing climate change adaptation or mitigation;
- covering different agri-food sectors;
- including both developing and developed countries;
- maturity of the use case (reaching at least the stage of Proof of Concept).

This has resulted in 9 use cases (see Appendix 2 for detailed documentation) from developing and developed countries and cover different agriculture sub-sectors (i.e. cash crops, livestock, fisheries and aquaculture, forestry, etc. as defined by FAO)³ as well as specific application of blockchain technologies across agricultural value chains. The use cases are described using a template based on the work of ISO TC on "Blockchain and distributed ledger technologies", specifically its working group ISO/TC 307/WG6.⁴ The purpose of using the template is to provide a structured overview of the key information of the use cases that enables analysis and synthesis. In consultation with the FAO team, the following aspects received special attention:

- The enabling environment, the uncertainties and the challenges for parties to step in;
- The governance model and the funding of the use case;
- The role for the public sector and the relationship between the public and the private sector in these use cases;
- The benefits for the farmer;
- The innovative aspect of the use case other than using blockchain;
- The relevance for public policy

In analysing the use cases, we use known theories such as the PESTEL (acronym for Political, Economic, Social, Technological, Environmental and Legal) framework (Craig and Campbell, 2012) and our own experience in organising and developing blockchain applications in various agri-food chains to examine the opportunities and challenges. Based on the findings, we then recommend priorities and options that may be used by FAO to advance its work in transforming the food system into more sustainable and transparent models that are resilient to the impacts of climate change.

³ http://www.fao.org/rural-employment/agricultural-sub-sectors/en/

⁴ https://www.iso.org/committee/6266604.html

3 Blockchain for climate change adaptation and mitigation (CCAM) in agriculture: Findings from the literature

3.1 Key aspects of blockchain application

3.1.1 General development of blockchain application

As observed by numerous studies, BCT is known to many as the technology underpinning the cryptocurrency Bitcoin and seems to follow the blueprint process for a technological hype as described by Gartner's hype cycle.⁵ The hype cycle distinguishes five phases of development for emerging technologies such as BCT: innovation trigger, the peak of inflated expectation, the trough of disillusionment, the slope of enlightenment and eventually reaching the plateau of productivity.

At the moment, cryptocurrency applications of BCT have muddled through waves of disillusionment and seem to be gradually climbing up on the slope of enlightenment. Similar trends are observed for the application of BCT in agriculture although the awareness of the technology and the 'peak of inflated expectation' have arrived later and were soon shadowed by the 'disillusionment' of developments in cryptocurrencies. As indicated in Figure 1, the period 2017-2018 has been an important phase of exploration for the applications of blockchain in agri-food and increasingly more use cases are identified and implementation expected since 2019 (Ganne, 2018; Ge *et al.*, 2017; Kamilaris, Fonts, and Prenafeta-Boldu, 2019).



Figure 1 The (expected) hype cycle of blockchain in agri-food

⁵ Available at: https://www.gartner.com/smarterwithgartner/top-trends-from-gartner-hype-cycle-for-digital-governmenttechnology-2018/

The last years have seen an explosion of interest in BCT with a great many companies and research institutions focusing on potential applications of this technology across a range of financial, industrial and social sectors. As the literature study suggests, BCT could provide a technological and economical method to create transparent, fast, standardized, and non-falsifiable records (Wright and De Filippi, 2015). BCT was considered of great relevance to the agri-food sector because agri-food transactions are fraught with trust and information management problems (see e.g., Sylvester, 2019; Tripoli and Schmidhuber, 2018). However, the technology has also been surrounded by a great deal of exaggeration and hype resulting in misplaced expectations and misunderstandings. BCT is still in an early stage of development, with considerable potential for real-life commercial applications. Innovation in blockchain architectures, applications and business concepts is happening at a fast pace. The rapid but unpredictable direction of blockchain innovation makes it particularly hard for commercial organizations and government agencies to make strategic decisions on how to respond to BCT. The growing number of applications makes it however possible to study and understand different facets of the technology and enables realistic assessment of the potentials and challenges.

3.1.2 Key components and attributes of blockchain application

Although often referred to as 'the blockchain', BCT is not a single technology, but a combination of technologies that have a considerable history in computer science and in commercial applications (see e.g., Swan, 2016). These component technologies include public/private key cryptography, cryptographic hash functions, database technologies especially distributed databases, consensus algorithms and decentralized processing (Atlam and Wills, 2019; IBM, 2016; Jim Brill *et al.*, 2016; Nakamoto, 2008a). Basic introductions to these components can be found in any of the websites listed in the section 'Introduction to blockchain' in the section 'References and websites'.

For practical application of BCT, it is important to have a basic understanding of what the technology includes, but also what it entails. This is necessary to assess the capabilities and limitations in addressing practical problems. In particular, which components and properties can be attributed to the technology and which cannot. To this end, a high-level conceptual architecture as shown in Figure 2 can be helpful to provide an overview of the building blocks.



Figure 2Key components of blockchain application (high-level architecture)Based on ITU Reference Architecture (ITU-T, 2019)

In general, what is commonly viewed as a 'blockchain application' consists of several layers of technology and governance arrangements that form different functional blocks as the following:

- decentralized application (DApp) functions (serving different business requirements in a distributed network environment);
- 2. resource and infrastructure functions (managing computer nodes, data storage, networks, etc.);
- 3. protocol/governance and compliance functions (ensuring consensus in the network);

- 4. operation & maintenance functions (including libraries such as log, monitoring, node/network management etc.);
- 5. external interaction management functions (interacting/interoperating with external systems);
- 6. extension functions (aiming to resolve different requirements of data interoperability, data interoperations of external systems such as 'side-chain', 'off-chain').

For each of these functions, there are many design choices to be made. Together, they shape the three layers of each blockchain application:

- the distributed ledger (data blocks, consensus algorithms, programming languages, etc.);
- the governance of using the ledger (accounts, right management, node management and the use of smart contracts);
- the ecosystem (actors and stakeholders involved in the blockchain application).

In the strict sense, blockchain refers only to the distributed ledger that consists of a series of data blocks linked to each other using cryptographic hashing functions to ensure its integrity and consistency. However, what is to be included in the data blocks and how new blocks are added to existing blocks depend on the governance of the ledger—the decision-making structure that sets the rules and protocols. This necessarily involves an ecosystem of human actors that translate their interests and power positions into arrangements and agreements. To understand the key aspects of blockchain application requires therefore a closer look at each of these three layers and how they relate to each other.

3.1.2.1 Distributed ledger, blockchain and consensus mechanisms

Distributed ledger refers to a type of database that is shared, replicated and synchronized among the members of decentralized network (Mainelli and Smith, 2015; Swanson, 2015; Walport, 2016). Blockchain is a type of distributed ledger in which a series of data blocks are linked to each other using cryptographic hashing functions. A hashing function is any function that can be used to map data of arbitrary size to fixed-sized values ('hash'). A hashing function is defined by two distinct characteristics: irreversibility (original data cannot be retrieved with the hash) and uniqueness (two different pieces of data should have two different hashes).⁶ A data block can be thought of as a page in a ledger that contains records of transactions, timestamp and hashes that are used to linked to previous blocks.

In decentralized systems, a consensus mechanism is required to ensure data consistency between different nodes. There are two modes for approaching this in DLT systems (ITU-T, 2019):

- State mode: consensus upon the states (results) of the world, mostly used for pre-execution of transactions on the ledger.
- Event mode: consensus upon events (transactions), mostly used for post execution.

A consensus mechanism is the core component of the distributed ledger and is used to ensure the consensus of all nodes on the data (Wang *et al.*, 2019). A 'node' is any physical device (computer, smart phone, iPad, etc.) within a network that is able to send, receive, or forward information. A personal computer is the most common node. The 'consensus nodes' are the ones that write the blocks to the ledger.

The consensus mechanism contains data consistency algorithms (also known as consensus algorithms), data validation, data distribution and synchronization. By use of the consensus mechanism, the distributed ledger system sets up a trust mechanism within the network. A trust endorsement module, e.g., incentive mechanisms, is then built upon that.

In general, the design of consensus algorithm should ensure the following:

- Consistency: Consensus nodes eventually need to agree on the data.
- Timeliness: Consensus nodes should complete the data consensus in as short a time as possible.
- Security: It takes a huge cost to undermine consistency and cannot be easily attacked.

⁶ More extensive explanation of hashing functions can be found at: https://komodoplatform.com/cryptographic-hashfunction/

Table 10 in Appendix 3 shows the commonly used consensus mechanisms. More extensive information and infographics can be found at many websites on the internet.⁷ In theory, a distributed ledger can use any algorithms that can meet the above requirements. However, their performances in speed, security, and availability may differ (Sayeed and Marco-Gisbert, 2019). It is therefore important to choose consensus algorithms that suit the purpose and meet the requirements of the application being developed.

At the level of the distributed ledger and consensus mechanisms, many choices need to be made for software implementation. The major choices are reflected in so-called blockchain frameworks. Blockchain frameworks are a software solution that simplifies the development, deployment, and support of technically complex products. The frameworks usually contain the basic technologies and modules enabling developers to extend or add specific components. Blockchain frameworks help developers work faster and more efficiently. Moreover, the variety of these frameworks is so large that every developer can choose one no matter how complex the project is. To illustrate this diversity, Table 11 in Appendix 3 provides an overview of most known blockchain frameworks with short comments on the pros and cons. It should be noted that the list is not exhaustive, and the advantages and disadvantages can be judged very differently, depending on the benchmarks used and the perspectives of the evaluator.

3.1.2.2 Governance

Governance of blockchain or blockchain governance is an important yet confusing aspect in blockchain application as the term is often loosely used by writers without a clear definition (Bohme *et al.*, 2015; Reijers *et al.*, 2016). The concept of governance itself also defies a universal definition. In different context, the term may consequently cover different aspects of governance. Notable efforts have however been made to provide consistent and operational frameworks to compare different blockchain systems (van Pelt, *et al.*, 2020)

From a practical perspective, a governance model describes decision-making both on the blockchain and off the blockchain. This includes the distribution of power to make and change the operating rules of the blockchain. In general, the governance model of blockchain application consists of different configurations of the following key elements (based on van Pelt, 2019; Motta, Tekinerdogan, and Athanasiadis, 2020; among others):

- participation, the extent to which participation of the blockchain application requires permission;
- access control, decisions with regard to who writes and reads a data block;
- the use of smart contracts, i.e., computerized transaction protocols;
- code governance, open source, community development, etc.

Participation

This can be 1) open or non-discriminatory: all actors have the right to participate in decision-making; 2) permissioned or exclusive: a limited number of actors have the right to participate in decision-making. It should be noted that besides the right to participate, there are also requirements for participation with regard to IT facilities (e.g., access to computer, smartphones or other devices, mobile networks and/or internet, etc.) and basic knowledge and skills (e.g., literacy). This may pose practical constraints on users who cannot meet these requirements and exacerbate existing gender and income inequalities, i.e., the 'digital divide' (Hughes, 2017). It is therefore often advocated to 'make more space for women on the blockchain' (Adams *et al.*, 2019). On the other hand, blockchain is also considered to be a technology that can help bridge the gender and income gaps as identities, ownerships and rights of women, children and gender minorities can be tracked and protected (Kamath, 2018).

Access control

This refers to the control of access to the ledger and related services. Controlling who writes and reads a block plays a vital role in every blockchain business solution. Broadly, there are three types of access control: private, public permissioned, public/permissionless (Buterin, 2015a; Gramoli, 2016). Consequently, this results in three different types of blockchain as summarized in Table 1.

⁷ For example: 1) https://101blockchains.com/consensus-algorithms-blockchain/#prettyPhoto/0 /; 2) https://www.newgenapps.com/blog/8-blockchain-consensus-mechanisms-and-benefits/

It should also be noted that to have access to a blockchain application, a user typically will require access to internet networks and internet enabled devices and basic education on digital services. Lack of access to these networks and services can practically restrict the access to blockchain applications.

Smart Contracts

The term 'smart contract' and the underlying idea dates from long before the emergence of blockchain technology. It was defined as a piece of computerized transaction protocol that satisfies contractual conditions such as payment terms, confidentiality or enforcement, reduces exceptions and minimizes the need for trusted intermediaries. For example, a smart contract could be programmed to release funds for a coffee farmer once the buyer confirms receipt of delivered coffee beans. Smart contract has received renewed attention in relation to blockchain due to its potential in automating transactions in a trustless network (Ante, 2020). It is generally acknowledged that smart contract has the potential of automating and simplifying business transactions and the audit trail of certification. It could also increase the transparency and reduce the cost of the interactions by creating legal constraints between the actors of the blockchain system. However, in its current application, the smart contract still does not have a legal application (Beck *et al.*, 2016; Buterin, 2015); Christidis and Devetsikiotis, 2016; Kosba *et al.*, 2016; Louise Lemieux, 2015; Ølnes, 2016; Wright and De Filippi, 2015).

The legal status and implications of smart contract have been widely discussed among scholars and practitioners (Drummer and Neumann, 2020; Schellekens *et al.*, 2019). In general, 'smart contract' is considered to have the status of a lawfully binding agreement when the parties involved can be identified. The complications arise when parties cannot be identified as is normally required in the physical world. The involvement of regulators and legal professionals like the notary may therefore remain necessary to enforce or interpret agreements.

Code governance

After deciding which user can access the ledger to read and to write, each blockchain application needs to define the peer participation to the project that can be open, technical or alliance (Bohme *et al.*, 2015; Nakamoto, 2008b; Yermack, 2017). As a consequence, the code license can be open and accessible to everyone or closed (Drescher, 2017). Finally, a company decides if the system should exchange information with another system outside the blockchain such as a hardware device, another blockchain or software (Niranjanamurthy *et al.*, 2018).

Table 1Comparison of different types of blockchain

	Public blockchain	Hybrid blockchain	Private Blockchain
Administrator: who installs and manages the blockchain?	Everyone, not identifiable	Limited number of known/identifiable parties	One party, identifiable
Is there a gatekeeper?	Yes, the algorithm	Yes (the initiator or the consortium)	Yes (the initiator or the consortium)
Are all users identifiable?	No	No	Yes
Who are validator nodes (consensus)?	Everyone	Decided by the gatekeeper	Decided by the gatekeeper
User with write rights	Everyone	Decided by the gatekeeper	Decided by the gatekeeper
Full read rights	Everyone	Everyone, except when explicitly agreed	Decided by the gatekeeper
Read via a front-end	Everyone	Everyone, except when explicitly agreed	Decided by the gatekeeper
Is the blockchain permissioned?	No	Possible	Yes
Is the software opensource?	Yes	Possible	Possible
How to make changes in protocol?	Very difficult	With consensus of all parties	Easy

The selection of the blockchain type depends highly on the objectives of the blockchain project, what type of value is exchanged and the characteristics of the actors involved in the application. Before

choosing the type of blockchain and its governance model, a more pertinent question to address is whether BCT is applicable as there are alternative systems (such as relational databases and document based webportals) for sharing data among different actors in the network. To this end, it is advisable to careful consider the applicability of BCT by going through the checklists listed in Appendix 3.

Theoretically, blockchain applications can result in the following governance and business benefits:

- **Disintermediation, or the removal of an intermediary in a process**. In a peer-to-peer network, there is no hierarchy or defined rules among the users; Additional collaboration arrangements or business schemes can be defined in the smart contract.
- **Transparency, traceability and accountability**. Blockchain can build trust among its users, accountability of the process due to the transparency of the transactions (Mainelli and Smith, 2015; Swan, 2016; Swanson, 2015; Walport, 2016).

3.1.2.3 Blockchain ecosystem

Blockchain is increasingly viewed as a collaborative physical and business ecosystem involving different devices, users, investors, operators, and IT solution providers (including providers and developers in IT infrastructure, software platforms and applications).

The physical ecosystem consists of a network of nodes. Each node is a computer, server, or storage device of some sort. In the case of full nodes, each contains an entire replica of the blockchain database, including every transaction that has been executed since its inception. Lite nodes contain only a partial transaction list but must be connected in some way to a full node to make sure that their data is accurate and useful. Some nodes are used for authenticating transactions, and others are simply used to access the blockchain's business services.

From a functional perspective, the blockchain can be seen as an ecosystem composed of a distributed database platform on top of which a number of interrelated software applications and services run. Each of these applications and services playing a separate but important role in the overall operation of the business. In short, the term 'ecosystem' is an apt description of an blockchain application as it recognizes it as an amalgam of all the parts that make up the whole and how they interact with each other within the system and then with the outside world (Gujral, 2019).

A generic characterization of the business ecosystem is depicted in Figure 3. Blockchain is well recognized as a "foundational technology that has the potential to create new foundations for our economic and social system" (Iansiti and Lakhani, 2017).



Figure 3 Generic blockchain ecosystem, based on Riasanow et al. (2018)

In a blockchain ecosystem, BCT has an infrastructural nature that can be used not only to develop cryptocurrencies and other digital assets but also for record keeping, digital notary, and smart

contracts in various processes and across industries, from banking, real estate and insurance to transport and agriculture. From the perspective of a business ecosystem, blockchain can also be seen as an institutional technology that solves coordination problems among actors with potentially conflicting interests for which intermediaries were used (Davidson *et al.*, 2018). The blockchain-based solution uses shared, distributed databases (ledger) to disintermediate transactions among economic agents. This new way of coordinating economic activities, where information and value are exchanged by the network that is connected to the blockchain system, could then be considered a new type of institution. Strategic aspects in which blockchains differ fundamentally from traditional/conventional organizations or institutions are governance, trust and openness.

Figure 4 provides an overview of the stakeholders and actors typically involved in a blockchain application. The roles and activities of the same actor can differ in different use cases. Notable roles of actors (such as third party implementation partner) and stakeholders are summarized in Table 12 in Appendix 3).

Different stakeholders from both a physical (technical) and organizational perspective take place in a generic blockchain ecosystem. A breakdown in Table 12 of possible blockchain consortium members, users and stakeholders aims to clarify the concepts used in this report, such as companies, stakeholders, actors, users and so forth. A stakeholder in general is any actor (person or organization) that has an interest in a (proposed) blockchain solution and can be an internal, indirect or external stakeholder. All stakeholders have influence on the solution to some extent, but the influence gets smaller as the stakeholder is moving to the outer layer.



Internal stakeholders

Part of the blockchain project, having direct influence on the solution, such as an organization that initiated the blockchain project, a direct user, or a partner providing data. Any other partner or Information Technology (IT) organization working on the project as part of a value chain is an internal stakeholder as well.

Indirect stakeholders

The middle layer of indirect, optional stakeholders could in some projects be an indirect user, for example an organization that shares certification data on a blockchain.

External stakeholders

An external stakeholder is in the outer layer and does not influence the blockchain solution itself, but can be influenced by or influence blockchain solutions in general by for example contributing to blockchain regulations.

Figure 4 Key actors in the blockchain ecosystem

3.2 Climate change adaption and mitigation in agriculture

3.2.1 CCAM strategies in agriculture

To understand the relevance of blockchain - essentially a registration and governance technology - to CCAM in agriculture, it is important to have a clear understanding of what CCAM activities are and how they are or can be registered (recorded and monitored) and governed (evaluation and improvement). To this end, FAO has developed an international classification to capture the full range of adaptation and mitigation components in agriculture and how national contributions can be evaluated (Crumpler *et al.*, 2019).

Climate change adaptation refers to changes in processes, practices and structures to moderate potential damages from climate change, or to benefit from opportunities associated with such changes (FAO, 2017).

Adaptation strategies include a broad set of activities to better manage climate risks. Climate change adaption in agriculture focuses mostly on the capacity to manage or moderate climate risks (including extreme climatic events), and the capacity to gradually respond to longer-term climate changes.

While adaptation aims to reduce the vulnerability associated with anticipated negative impacts of climate change, climate change mitigation refers to reducing and possibly stabilizing the GHG concentrations in the atmosphere. The negative impacts in agriculture include first of all the loss of social-economic welfare among food producers, especially smallholder producers in developing countries (Donatti *et al.*, 2019). Such negative impacts also include the loss of agro-ecosystem services and biodiversity for food and agriculture (FAO, 2019). These agro-ecosystem services are needed to buffer against disasters, enhance carbon sinks, and support adaptation through the adoption of resilient and sustainable agricultural practices (e.g., nature-based solutions, NbS) (Cohen-Shacham *et al.*, 2019). Blockchain could be used to support new business models for climate adaptation, where capital is provided for food producers to adopt improved land use and management practices combined with rewarding schemes. Rewarding schemes could be based on existing schemes (like Rainforest Alliance,⁸ etc.), but a blockchain initiative could also start a new scheme on its own through the smart contract.

The agricultural sector has a substantial potential for mitigation. According to the Intergovernmental Panel on Climate Change (IPCC) Special Report on Climate Change and Land, agrifood systems currently contribute up to more than 30 percent of global greenhouse gas emissions, accounting for agricultural production, land-use changes and energy consumption derived of processing (IPCC, 2019). In the agricultural sector, there are three major options that introduce resilient and sustainable management practices aimed at:

- Reducing emissions: Agriculture releases to the atmosphere significant amounts of CO₂, CH₄, or N₂O. The fluxes of these gases can be reduced by more efficient management of carbon and nitrogen flows in agricultural ecosystems, leading to less carbon dioxide, nitrogen and methane released. More specifically, there are two subcategories of reduction, namely absolute decrease in emissions levels, and relative to the production (efficiency aspect).
- Avoiding or displacing emissions: The energy efficiency of the agriculture sector can be improved. In addition, fossil fuel energy used in agricultural production can in some cases be replaced by biofuels and renewable energy. Greater use of wood products can also lead to displacing CO₂ emissions. Note that unsustainable use of wood products could contribute to deforestation. A problem related to the use of biofuels is that it could lead to the destruction of forest to make space for biofuels and competition with food crops.
- Removing emissions: GHGs can be absorbed from the atmosphere through sinks. A sink is any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas or aerosol from the atmosphere.

A concept closely related to CCAM is climate smart agriculture (CSA) which can be defined as "an approach that helps to guide actions needed to transform and reorient agricultural systems to

⁸ Available at: https://www.rainforest-alliance.org/

effectively support development and ensure food security in a changing climate. CSA aims to tackle three main objectives: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible" (FAO, 2020b). Within the concept of CSA technologies are promoted that either increase farmers' resilience to related climate hazards (adaptation), or contribute to climate change mitigation, or both (FAO, 2020b; Rosenstock *et al.*, 2016).

It is increasingly realized that adaptation and mitigation should not be pursued independently of each other but seen as complements. Adoption of CSA technologies requires that smallholder farmers consider these practices suitable for their purposes and resources and contributing to their livelihood preferences. However, mitigation efforts commonly face an essential problem that private returns are commonly negative so farmers need to be encouraged by means of, for example, subsidies, or externalities taxed or by means of a regulatory framework concerning certain compliance standards (Ruben *et al.*, 2018). The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) uses a typology comprising five climate-smart options (CCAFS, 2016):

- **Weather-smart** activities provide weather information to the farmers so they would be able to make better decisions regarding their farming as well as weather insurance.
- Water-smart activities enhance better management of water, as protection against water scarcity or floods.
- **Seed/breed-smart** activities introduce new crop seeds or animal breeds that are better adapted to changes in temperatures or rainfall.
- **Carbon-smart** activities reduce or even remove greenhouse gas emissions from the production process. Nutrient- and pest-smart practices are those that maintain sustainability while ensuring nutrient and pest management.
- **Institutional/market-smart** activities cover a variety of practices of a more socioeconomic nature.

CSA practices are incredibly diverse and reflect the context-specificity of opportunities, constraints and vulnerabilities (Sova *et al.*, 2018). There is a growing divide within the CSA discourse that lacks conceptual clarity (Chandra *et al.*, 2018). Lack of conceptual clarity about the range of potential farm-level CSA practices across contexts impedes understanding of CSA adoption in developing countries (Amadu *et al.*, 2020). In this study, we therefore adopt a generic approach to distinguishing climate change adaptation and mitigation activities in different use cases as shown in Figure 5, while acknowledging that some use cases may contain both activities.



Figure 5 Climate Change and CCAM activities Source: IPCC2001

3.2.2 Opportunities and challenges in registering and governing CCAM in agriculture

There is a rich body of literature on the opportunities and challenges of CCAM in agriculture, both in developing and developed countries. Using the TopicGuide module of Leximancer, we have derived key CCAM options and research topics discussed. Table 2 provides an overview of the CCAM topics discussed with informative references. Following IPCC (2001) (cf. Figure 5), we classify these options as being climate change adaptation or mitigation whereby we make a distinction between different development paths since these will shape future vulnerability to climate change, and climate change impact may affect prospects for sustainable development.

In general, research on climate change mitigation is centred around carbon and GHG, while research on climate change adaptation has a much broader purview. The diversity of topics and issues offers on the one hand many opportunities to apply BCT, on the other hand also presents a wide range of challenges.

Dovelopment noth	Climate Adaptation	Climate Mitigation
Economic development	 Rural financing (Linnerooth-Bayer and Hochrainer-Stigler, 2015; Ruben <i>et al.</i>, 2018) Microfinance (Fenton <i>et al.</i>, 2015) Social impact investment (Roundy, 2019) 	 Clean energy (Hussain <i>et al.</i>, 2019) Low-carbon livestock (Feng, 2012) Agroforestry (Tschora and Cherubini, 2020) Carbon credits and carbon trading (Kim and Huh, 2020; Pan <i>et al.</i>, 2019)
Technological innovation	 Sustainable intensification (Godfray and Garnett, 2014; Thomson <i>et al.</i>, 2019) Carbon and Nitrogen Management Options (Wiebe <i>et al.</i>, 2019) Nature-positive/Green infrastructure practices (Adenle <i>et al.</i>, 2015) 	 Carbon offset (Lovell, 2010; Mackey <i>et al.</i>, 2013) Reforestation (Locatelli <i>et al.</i>, 2015) Carbon sequestration (Scherr and Sthapit, 2009) Carbon removal (soil sequestration) (Muller, 2012; Smith <i>et al.</i>, 2020)
Demographic development	 Inclusiveness Gender equality (Daniel and Ifejika Speranza, 2020) Labour conditions (Senou <i>et al.</i>, 2019) Healthy diet (Malik <i>et al.</i>) 	 Sustainable diet (Lake <i>et al.</i>, 2012) Population size and structure (Lutz and Striessnig, 2015)
Governance	 Empowerment and capacity building (Thomason <i>et al.</i>, 2018) Rural livelihood (Lin <i>et al.</i>, 2017) Human rights, living income (Wilshaw, 2018) 	 Carbon labelling (Birkenberg <i>et al.</i>, 2020) Climate ledger initiatives (Fuessler <i>et al.</i>, 2018)

Table 2	CCAM Options and topics in Agriculture
---------	--

The transformation to foster adaptation and mitigation is challenging. More nuanced and effective targeting of technological as well as institutional interventions is needed for agricultural adaptation to meet the climate change challenges (Thornton *et al.*, 2018). Mitigation options could also bring significant challenges, because the cost of production will likely increase, and the deployment of new technologies will require some significant restructuring of the sectors. Moreover, a comprehensive accounting of GHG emissions presents considerable challenges in terms of monitoring transactions and implementation in general (Havlík *et al.*, 2015).

Furthermore, ethical issues in terms of fairness and inclusiveness are frequently discussed since adaptation and mitigation may have negative side effects on those who are more vulnerable (children, women, the poor, disabled). Hence, the literature review suggests the following key challenges in CCAM in agriculture in the adoption and governance (incentivize, monitoring and accounting) of transactions. Accounting mitigation is especially challenging due to the problem of carbon leakage (Engel and Muller, 2016; Fellmann *et al.*, 2018; Muller, 2012; Scherr and Sthapit, 2009) and the permanency aspect when considering carbon sinks (soil or biomass), as most 'solutions' are reversible.

3.3 Blockchain and CCAM in agriculture

3.3.1 Blockchain for climate change in general

As stated by many institutions (e.g., UNDP,9 WEF),10 newly evolving technologies such as blockchain technology have the potential to act as a tool to accelerate global actions towards the Paris Agreement agenda and the Sustainable Development Goals (SDGs) of the Agenda 2030. There is a wealth of literature on blockchain for climate change, mostly of the exploratory nature and still on the conceptual level (Chen, 2018; Hartmann and Thomas, 2020; Howson, 2019; Mata Dona, 2019; Sharma, 2017).

Global initiatives such as the Blockchain for Climate Foundation¹¹ are emerging on applying blockchain for facilitating and governance activities on climate change adaptation and mitigation globally. It is believed that national accounting of GHG emissions reductions, connected through a ledger recording international transfer of emissions reductions, enables transparency and accountability of all actors. Similarly, financial flows can originate from anyone and anywhere in the world, directed towards specific projects under pre-defined conditions, and with a tamperproof documentation of every transaction. Blockchain has also been considered relevant for the conservation of biodiversity that is under threat by climate change (Kouhizadeh and Sarkis, 2018).

The application of blockchain for climate change is not without controversies. For instance, there are increasing concerns that 'electronic' or 'computational'-based solutions are also having a big impact in terms of CO₂ emissions (mostly energy consumption of the servers and mining pools) and also environmental impact (Krause and Tolaymat, 2018; Stoll *et al.*, 2019). There are rather provocative statements regarding the use of bitcoin systems and systems using cryptocurrencies.¹² The energy consumption of blockchain has raised concerns and is subject to active research and development of both academia and blockchain technologists. The estimates of the Bitcoin electricity consumptions are between 60 and 125 TWh per year. This is in the range of the annual electricity consumption of countries such as Austria (75 GWh) and Norway (125 GWh) (SedImeir *et al.*, 2020). However, blockchain technology is far from homogeneous. Energy consumptions per transaction have a large variation across blockchain architectures (SedImeir *et al.*, 2020).

The consensus mechanism of a blockchain is a determining factor for the energy consumption patterns of a blockchain. The consensus mechanism is responsible for making decisions in the blockchain network. Bitcoin uses the Proof of Work (PoW) consensus mechanism, which is energy intense. The Proof of Stake (PoS) has a lower energy consumption and will be part of the next version of Ethereum (Eth2). The topic of energy consumption of the various consensus algorithms is subject to intense development and research. New blockchains like Hedera HashGraph¹³ and Zilliqa¹⁴ arise on the horizon that use alternative consensus algorithms like hash graph or practical Byzantine Fault Tolerance (pBFT). This likely will improve the energy consumption patterns, it is unlikely that it will break even with centralized systems.

SedImeir *et al.* (2020) refers to work of both Vranken (2017) and Mora (2018), where Vranken contributed later to an article that disputed the work of Mora (Masanet *et al.*, 2019). This indicates the intensity of the discussion on energy consumption of blockchain and its measurement methodologies. Literature does agree on the fact that high energy consumption patterns mainly apply to public blockchains that use a PoW consensus mechanism. Enterprise blockchains or blockchains with energy friendly consensus mechanisms have a considerably lower energy consumption.

⁹ See https://unepdtu.org/wp-content/uploads/2019/02/udp-climate-change-blockchain.pdf

¹⁰ See http://www3.weforum.org/docs/WEF_Building-Blockchains.pdf

¹¹ See https://www.blockchainforclimate.org/

¹² For online discussions see: https://www.iea.org/commentaries/bitcoin-energy-use-mined-the-gap; https://www.robeco.com/en/insights/2019/04/spending-one-bitcoin-330000-credit-card-transactions.html; https://www.vox.com/2019/6/18/1864245/bitcoin-energy-price-renewable-china

¹³ Available at: https://www.hedera.com/

¹⁴ Available at: https://www.zilliqa.com/

SedImeir *et al.* (2020) reason that PoW blockchains are not a large threat to the climate because the energy consumption does not increase substantially when more transactions are processed. This premise is valid, providing the current energy consumption of Bitcoin is not perceived as a large threat to the climate as of today. Furthermore, SedImeir argues that the energy consumption of blockchain must be weighed out against its energy savings through its inherent digitization process.

3.3.2 Blockchain applications in agriculture

As noted by many, the number of blockchain applications has been rapidly rising in agriculture and food (Howson, 2020; Motta *et al.*, 2020). Many companies are providing services tracking the blockchain ecosystem.¹⁵ Most of the implementations are pilot-projects that are still on-going or only carried on for a brief period. It is often unclear or kept confidential which aspects of blockchain technology are used, how they are used for implementation and what their influences are. Table 3 provides an overview of current applications in agriculture and the relevant topics.

Problems addressed	Relevant topics	Aspects	Applications
Lack of trust	Transparency	- Identity management	- Risk management
		- Events management	- Anti-corruption
		- Auditability	- Authenticity of agri-food products
	Traceability	- Provenance	 Marketing premium products
		 Tracking & tracing 	(organic, PDO)
		- Accountability	 Reducing food waste
			- Digital product passports (origin
			and provenance)
	Information integrity	- Reliable information	- Quality certification
		- Data validation	- Quality assurance
		- Data provenance	- Fraud prevention
			- Data passports
	Consensus	- Business rules and	 Supply community
		agreements	 Supply chain traceability
			 Supply chain finance
New value creation	Fairness	- Inclusive business model	 Living wage for smallholders
/distribution			- Monitoring and enforcing labour
			conditions (slavery, child labour,
			gender equality)
	Efficiency	- Value chain structure	 Short supply chains
	Nature-based Solutions	- Conservation of bio-diversity	- Monitoring use of pesticides
	(NbS)	- Transparency and	- Natural capital
		accountability of pesticide use	- Biodiversity index
		(WEF, 2018)	

Table 3Overview of topics and applications in different blockchain use cases in agriculture

That many use cases in agriculture use the blockchain framework Ethereum and tokens can raise concerns about the energy consumption of the blockchain applications elsewhere due to the mining of tokens. Critics consider initiatives like EverGreenCoin and TreeCoin planting trees to offset the extensive energy consumption associated with verifying and maintaining cryptocurrency transactions (De Vries, 2018). More empirical research is needed to verify whether the energy consumption of mining would offset the impact of mitigation.

The challenge is also how to identify and prove the unique added value of BCT with reference to existing alternatives. For example, blockchain-based traceability system may be less efficient compared to existing traceability systems that uses centralized databases. An illustrative example is the case of the chocolate company 'Tony's Chocolonely' (Ellebrecht, 2019). The brand decided not to proceed with their blockchain pilot, which had gained great visibility, due to the lack of 'additionality',

¹⁵ See e.g. Blockdata available at https://www.blockdata.tech)

i.e., unique contribution of the blockchain to the objective of the organization in addition to their existing transparency/traceability system. 16

3.3.3 Blockchain for CCAM in agriculture

Agriculture is increasingly acknowledged as part of the solution to climate problems (IPCC2019). In this context, a number of applications for blockchain technology have emerged that are directed at CCAM in agriculture and many potential ones are being discussed. Corresponding to the three layers of blockchain application, we have developed a framework to map these blockchain applications for CCAM in agriculture as shown in Figure 6. In this framework, we look at activities aiming at reducing emissions and concentrations as climate mitigation and those aiming at addressing climate change impacts as climate adaptation. The layer of the distributed ledger is the bedrock of all applications where emissions and concentrations and climate change impacts are registered and monitored.



Figure 6 Blockchain for Climate Change

Following this framework, Table 4 summarizes the blockchain features that are relevant to CCAM in agriculture. This mapping is also used to closely examine the shortlisted use cases.

¹⁶ See https://www.cryptonewsz.com/tonys-chocolonely-company-uses-blockchain-technology-to-fight-slavery-from-thechocolate-industry/

Blockchain features	Climate Change Adaptation	Climate Change Mitigation
Distributed Ledger	- Registration of identities and	 Monitoring & Accounting of:
	ownerships (Sylvester, 2019)	- Carbon permits
	- Registration of land title (Vos, 2017)	- Carbon emission
	 Registration of credit/savings (Bolt, 	- Carbon offset
	2019)	- Reforestation
Smart Contract	- Climate financing	- Carbon trading
	- Microinsurance	 Carbon labelling & certification
	- Rural credit	- Traceability
Ecosystem/Governance	- Community building	- Carbon market building
	- Trust building	- Transparency and accountability mechanism
	- Data sharing	- Trust building
		- Data sharing

Table 4 Overview of potential blockchain applications for CCAM in agriculture

3.3.4 Challenges in applying BCT to CCAM in agriculture

When addressing the opportunities of BCT for CCAM in agriculture, it is important to also look at the incentives and challenges for different actors and alternative systems to address the same opportunity or problem. The incentives for the development and adoption of BCT or DLT in general vary across different areas of application and stakeholder groups. As users of blockchain application, the benefits can be cost-reductions, new revenue streams, or both. Cost reduction is achieved through disintermediation and increased efficiency, while new revenue streams are generated through removal of technological and operational barriers, thus enabling new types of services or applications.

In the current state of digitalization, there are many challenges to be addressed for applying BCT to CCAM in agriculture. Figure 7 visualizes these challenges along the agricultural data chain in which data on various aspects of CCAM in agriculture are captured, processed and shared. The availability and reliability of input data is a well-known 'first mile' problem in blockchain and other data-driven technologies in agriculture (Antonucci *et al.*, 2019). A related problem is the diversity of data definitions and metrics that hinders interoperability of data across different systems (Ge *et al.*, 2017; Motta *et al.*, 2020). Combatting climate change globally requires collaboration and data sharing. To facilitate data exchange in the carbon data community, standardization of methodologies and measurements will be a major challenge.

In the short run, applying BCT to CCAM in agriculture may require significant investment for data collection and digital infrastructure before expected benefits of transparency and automation can be realized. Integrating the blockchain with the current traceability hardware and systems via Internet of Things (IoT) combination could lead to better integration and performance of the devices used in the agri-food industry (Christidis and Devetsikiotis, 2016; Kumar *et al.*, 2017; Tian, 2016).



Figure 7 Challenges of blockchain application in agriculture

4 Blockchain applications for CCAM in agriculture: Findings from the use cases

4.1 Application of blockchain for CCAM in agriculture

Our search resulted in a long list of use cases related to CCAM in agriculture. This suggests a high level of awareness of the technology in the sector. Following the selection criteria, we studied 9 use cases in detail. Table 5 summarizes their basic features. Detailed descriptions of these shortlisted use cases can be found in Appendix 2. The diversity of the use cases enabled us to compare different applications in developing and developed countries with different motivations and steps taken.

Although not directly targeting climate, there are many other blockchain use cases in the agriculture sectors that are of relevance to CCAM. Notable examples are Moyee Coffee¹⁷ that sells the world's first 'blockchain coffee' which offers a fair coffee price for smallholder farmers to improve their income and sustainability, and Nestlé's pilot that aims to trace milk from farms and producers in New Zealand to Nestlé factories and warehouses in the Middle East and palm oil sourced in the Americas.¹⁸ In the same vein, Oxfam's blockchain project BlocRice¹⁹ aims to help farmers to combat poverty and the NGO Fairfood²⁰ has demonstrated the value of blockchain in improving smallholders' income in several food value chains (i.e., coconut, coffee, and spices). The blockchain application AgriLedger²¹ provides ledger services that are aligned with multiple SDGs including gender equality (SDG5) and climate action (SDG13).

Use case	Region	Year of Establishment	CCAM activities	Agrifood sector
AgriDigital	Australia	2015	Adaptation, transactions, new value chains	Grain, crops
Agri-wallet	Kenya, Asia	2016	Adaptation, financing	Crops
Beefchain	US	2018	Mitigation, traceability, transactions	Livestock
EthicHub	Mexico, Africa	2017	Adaptation, finance, crowdlending	Non specific
Insurance	Sri Lanka	2017	Adaptation, finance, microinsurance	Paddy rice farming
Land LayBy	Kenya, Ghana	2018	Adaptation, finance, land rights	Non specific
Nori	US	2018	Adaptation & Mitigation, carbon market	Arable farming
Poseidon	Global	2019	Adaptation/Mitigation	Agroforesty
Treecoin	Switzerland, Paraguay	2018	Mitigation, carbon sequestration	Forestry

Table 5 Overview of use cases using blockchain for CCAM studied in detail

¹⁷ See https://www.moyeecoffee.com/

¹⁸ See https://www.nestle.com/media/pressreleases/allpressreleases/nestle-open-blockchain-pilot

¹⁹ See https://www.oxfamamerica.org/explore/stories/can-blockchain-help-rice-farmers-fight-poverty/

²⁰ See https://fairfood.nl/

²¹ See http://www.agriledger.io/home/

4.2 Enabling environment and challenges for the use cases

To obtain more insight into the enabling environment for the use cases, we used the PESTEL (i.e., Political, Economic, Social, Technological, Environmental and Legal) framework to identify relevant factors. This includes understanding the institutional framework related to blockchain for CCAM, policies, strategies and laws (including incentives) favouring or hindering the development and adoption of blockchain applications as well as economic, social, technological and environmental conditions that were conducive to the use cases. The main features are summarized in Table 6.

Overall, the enabling institutional framework consists of favourable national and international policies towards CCAM in agriculture and digital solutions in terms of strategies and instruments (subsidy, grants and availability of land) and supportive governmental organizations. Economically, the rising popularity of platform financing and the development of carbon credits and carbon trading appear to be the major pulling factor, while internet, digital platforms and IT solutions (fintech) provide the technological push and support. From a social perspective, the applications thrive on ethical concerns for climate change and inclusiveness, as well the demand for improved transparency and accountability in carbon offset programs and market for carbon credits and emission rights. NGOs are playing a prominent role in empowering smallholders.

Usecase	Institutional framework (political, legal)	Economic	Social	Technology	Environmental
AgriDigital	National policy to develop digital economy including fintech	Collaboration of large trading corporations (e.g., CBH group)	Demand for digital trust and transparency, farmers facing payment delay	Mobile networks	Unidentified
Agri-wallet	Policy on digital agriculture	Willingness of banks to provide loans	Smallholder farmers in need of digital finance	Coin22 providing IT solutions	Unidentified
Beefchain	USDA certification	Market for premium products with end-to- end traceability	Consumers value traceability and chain transparency	University providing blockchain code, RFID	Free-range grass land
EthicHub	Global attention to financial inclusion	Commodity contracts; Inter-American Development Bank (IDB)	Concerns for small farming communities, Transparency and peer-to-peer highly valued, support	Working blockchain-platform (Ethereum-based), low entry requirement	Unidentified
Insurance	Global attention to financial inclusion	Well established (re-)insurance market	Concerns for vulnerability of smallholder farmers	Decentralized Insurance Protocol	Risk of extreme weather
Land LayBy	Financial inclusion, Importance of improving African land registry system	Active transactions in land ownership	Corruption and fraud in land titles; Fintech communities in Kenya	dApp platforms such as Ethereum	Unidentified
Nori	Favourable environment for the use of crytocurrencies for climate change governance ('crytogovernance')	Development of carbon credit market	Improved public understanding of carbon offset and scrutiny of carbon offset programs	Guidance from ISO 14064-2:2019 for developing methodologies	Natural reserves

Table 6 Enabling environment for CCAM studied in detail

Usecase	Institutional framework (political, legal)	Economic	Social	Technology	Environmental
Poseidon	Peru's national REDD+ programme	FCC (forest carbon credit) available	Consumers' interest in carbon credit, forest conservation and rural communities	Standardized methodology to calculate and trade carbon credit	Stellar blockchain consumes less energy
Treecoin	Supportive government (project subsidized), favourable investment policy	Stable market for global investors	Global concerns for deforestation	Fast-growing tree, ICO/HTO for fund raising	Favourable climate and availability of fallow lands in Paraguay

In addition to the enabling environment, we also looked at the uncertainties and challenges for different parties to step in the blockchain projects. For initiators and operators of blockchain applications, the main challenge is how to acquire sufficient funding and technological resources for initial development and operations. Once the project is up and running, the major challenge is to attract investment and sufficiently large number of users for scaling up. For investors, the main challenge was the complexity and evolving nature of the technology which makes the success and return on investment uncertain.

The complexity of the technology and lack of empirical evidence on the ground regarding the effectiveness and added value of blockchain applications constitute a major challenge for public actors, non-profit private actors or impact investors to engage or invest in blockchain projects. For regulators and public sector actors, the challenge is how to set the regulatory framework and safeguards without impeding innovation.

4.3 Use of blockchain features in the use cases

As elaborated in Section 3.1.2, blockchain is not a single technology and has many layers and features. The shortlisted use cases demonstrate this multidimensionality. In Table 7, the main blockchain features used by the 9 use cases are summarized. In terms of blockchain frameworks, Ethereum is no doubt the most popular one and all use cases make use of tokens and smart contracts, either to raise funds to finance the project (e.g., EthicHub, Nori and Treecoin) or to facilitate transactions (e.g., AgriDigital, Agri-Wallet and Beefchain).

For climate change adaptation, the governance benefits of the blockchain include disintermediation, therefore improved access to finance and less risk and transaction costs (e.g., AgriDigital, EthicHub, Insurance, Land LayBy) for climate change adaptation. For climate change mitigation, transparency, traceability and accountability are the main reason BCT is used (Nori, Treecoin and Poseidon).

Use case	Blockchain framework	Ledger	Smart Contract	Business benefits	Governance benefits
AgriDigital	Quorum (Ethereum-based)	Ownership of commodity (grains), transactions	Transactions	Efficiency, speed of payment	Accountability, Improving trust and transparency, Reducing counterparty risk
Agri-wallet	Ethereum	Ownership, credit, saving, transactions	Credit & transactions	Better access to finance, improved productivity and sales	Improving financial resilience of smallholder farmers
Beefchain	Ethereum	Ownership (beef)	Traceability & transactions	Capture premium pricing	Traceability, Quality assurance
EthicHub	Ethereum	Ethix, digital credit	Financing, credit and payment	Better access to finance with lower transaction costs	Accountability, traceability
Insurance	Ethereum	Credit	Financing and transactions	Better access to finance with lower transaction costs	Accountability, traceability
Land LayBy	Ethereum	Land title	Transactions	Activating land as capital	Transparency and accountability
Nori	Ethereum	Carbon removal credits	Carbon removal transactions	Carbon credit market with lower transaction fees	Traceability
Poseidon	Stellar (based on Ripple)	Carbon credits	Financing and transactions	Enabling carbon credit markets for consumers	Accountability
Treecoin	Ethereum	TREE (token)	Financing, investment	Investment opportunities	Traceability & accountability

Table 7 Overview of blockchain features used in the use cases

4.4 Blockchain ecosystem and the role of the public sector

Ecosystem is one of the defining features of blockchain application. It is also one of the most challenging one to characterize and generalize. Typically, each use case has its own ecosystem with different actors and governance models (see in Appendix 2 more details on the actors involved in each use cases). Ecosystem functions such as funding and coordination are also performed by different actors. In light of the research objectives and questions, we have summarized a number of main features of the ecosystems for the use cases in Table 8.

Although the ecosystems for these blockchain usecases came into being through different paths, some patterns can be observed with regard to the governance model and the role of actors from the public sector. The 9 use cases are mostly funded by private funds (by private companies, private investors or crowdfunding through ICO), with the support of public actors in the form of grants, awards and supporting services. Many projects started as innovative ideas at hackathons or similar events. The initiators are mostly private actors in the value chain, with actors from the public sector mostly playing supported roles. Actors in the public sector are NGOs, standardization organizations and governments. The City Council of Liverpool is in a partnership with Poseidon to offset more than 110 percent of its carbon emissions to become a climate-positive city by the end of 2020.²²

²² https://www.liverpool.ac.uk/architecture/events/archive/poseidon/
Table 8 Main features of the blockchain ecosystem in the use cases

Use case	Public actors	Private actors	Funding	Operations	Users	Participation	Inclusiveness
AgriDigital	Unidentified	Farmers, traders, banks	Private	AgriDigital (start-up)	Professional farmers and	Permissioned	Non-discriminatory
Agri-wallet	Worldbank, IDH (NGO)	Fintech companies, Farmers, traders, banks	РРР	Dodore (IT services	Smallholder farmers and	Permissioned, free	Smallholder farmers, especially women
Beefchain	Background (USDA for certification)	Cattle farmer,	Private	BeefChain.io (company)	Cattle farmers and buyers	Permissioned	Non-discriminatory
EthicHub	Unidentified	Coffee farmers, banks	Private, ICOs	LendingDev (AgTech company)	Smallholder farmers and investors	Permissioned	Smallholder farmers, especially women
Insurance	Oxfam (NGO)	Insurance companies	Private, ICOs, utility tokens	Etherisc (start-up)	Smallholder farmers and insurance companies	Permissioned	Smallholder farmers, especially women
Land LayBy	Background (Ministry of land registry)	Tech company	Private, ICO	Land LayBy (start-up)	Smallholder farmers and insurance companies	Permissioned	Non-discriminatory
Nori	Techstars Sustainability Cohort (NGO, technical standards)	Farmers, Agro-IT solution providers	PPP, ICO	Nori (climate start-up)	Farmers, investors	Open	Non-discriminatory
Poseidon	Liverpool City Council	Commodity companies, IT companies,	РРР	Poseidon (climate start- up)	Farmers, Consumers	Open	Non-discriminatory
Treecoin	Government (subsidy & investment policy)	Investors, tree growers, blockchain community	Private, ICO, HTO	GlobalTree Project AG	Consumers	Open	Non-discriminatory

4.5 Impact and benefits for the farmer

As noted by many, there is a great deal of hype and exaggeration around blockchain applications. It is often not easy to verify the actual impact claimed in marketing stories. Nevertheless, the large amount of secondary information on the internet regarding these use cases made it possible for us to obtain indicative impact. Table 9 summarizes the expected business benefits in terms of business volume and the beneficiaries as well as the potential impact on climate change. The latter is especially relevant for the cases on climate change mitigation.

It should be noted that the quantified impact is based on secondary information public available and may not correspond to reality/actual situation. As most projects are still ongoing, their actual effects on climate adaptation and mitigation remain to be seen. Currently, no gender-disaggregated data is available with regard to the users and beneficiaries. For policy and learning purposes, it is advisable to closely monitor and evaluate the progress and impact, especially when they concern SDG goals. To address the gender issue, gender-relevant SDG indicators²³ should be further developed and monitored.

In addressing the benefits of blockchain applications for farmers, we note in these use cases that different groups of farmers participate in blockchain applications. Smallholder farmers are generally the end users. Professional farmers are sometimes initiators and operators of blockchain application (e.g., BeefChain and AgriDigital). Users of blockchain-based microfinance and microcredit (Insurance and EthicHub) are mainly smallholder farmers, although insurance companies and traders also benefit from increased sales and market volume (e.g., Agri-Wallet and Insurance).

Use case	Business volume (Transaction volume/Market capitalization of tokens)	Beneficiaries	Climate impact
AgriDigital	AUD 1 224 million / 6.27 million tonnes of grain	More than 4 000 active users across 36 countries, mostly grain farmers.	Unidentified
Agri-wallet	Annually value creation of EUR 50 million expected	Smallholder farmers (>25 000) with access to credit, input suppliers (higher sales)	Unidentified
Beefchain	Price premium of more than 10 cents/pound beef	Cattle farmers and consumers	Organic cattle ranching, grass-fed cattle
EthicHub	Softcap USD 500 000; Hardcap USD 1 500 000	200 smallholder farmers enrolled, targeting 5 000 farmers	Unidentified
Insurance	No information available	200 smallholder farmers enrolled in 2019, 5 000 targeted in 2020	Insurance against extreme weather risk
LandLayBy	285 714 Harambee (1HRBE= USD 0.7)	Smallholder farmers	Unidentified
Nori	Price of NRT is 1 NORI token, value set by market. 1 tonne = USD 15 (Sept 1st 2020) * 811 433 = USD 12 171 495	About 50 farmers at various accounts at different stages in the enrolment process. One farmer participates in paid platform.	811 433 tonnes (CO ₂ equivalent) purchased
Poseidon	2 421 832 (value of tokens sold in ICO)	Local communities (and eco- systems), consumers	22.1 million tonnes of CO_2 by 2021
Treecoin	Softcap EUR 15 million	Tree growers, Rural communities, Disadvantaged people, small investors	Expect to plant 12 000 hectares with 10 million Eucalyptus trees in coming 10 years

Table 9	Overview of business	benefits and climate	impact of the use cases
---------	----------------------	----------------------	-------------------------

²³ Based on for example:

https://unstats.un.org/unsd/demographic-social/gender/documents/14Mar2018_Gender_relevant_SDG_indicators_MB-HSS.pdf

4.6 Outlook for blockchain application for CCAM in agriculture

BCT is still evolving, and so are blockchain applications for CCAM in agriculture. New blockchain frameworks and applications continue to emerge as the popularity of some existing applications began to wane. While it is difficult to predict what exactly may happen in the future, we may similarly use the PESTEL framework to shed light on the outlook for applying BCT to CCAM in agriculture. Given the opportunities and challenges identified, the future of blockchain application in CCAM in agriculture depends on:

- regulatory frameworks regarding the governance of CCAM activities and the use of DLTs and cryptocurrencies;
- the development of digital economies, especially the inclusion of rural areas;
- the development of the global carbon market;
- consumers' role in the transformation towards more responsible, climate neutral, inclusive and resilient and sustainable food systems;
- technological development regarding the performance, interoperability and scalability of DLT systems;
- willingness to share data among actors along the global carbon data chain, consent to share private data on or via the blockchain;
- digital capabilities: level of capabilities to use, program and regulate the blockchain

From a regulatory or governance perspective, it is critical for regulators and other public actors, among which FAO, to address CCAM problems with clear view and guideline on what kind of transparency and which indicators they should monitor, incentivize and reward through the application of blockchains. For researchers and project developers, it is important to take ethical considerations into account and pay attention to effective ecosystem development in multi-actor processes. In this regard, much work has been done in the frameworks of responsible research and innovation (RRI) and value sensitive design for information systems in projects such as the IOF2020.²⁴ For policy makers and other social actors, it is important to decide whether blockchain is used to monitor business-as-usual practices or also be used to give more purchasing power to consumers, enabling them to be more active participants in the transformation towards more sustainable and inclusive food systems.

Through the lens of technological development, ongoing efforts in standardization is expected to improve interoperability and the scalability and foster innovation. Currently, ISO, the International Organization for Standardization²⁵ is developing the following standards:

- Terminology and concepts (2020)
- Overview of privacy and personally identifiable information protection (no date)
- Security risks and vulnerabilities (no date)
- Overview of identity (no date)
- Reference architecture (2021)
- Taxonomy and Ontology (unclear)
- Legally binding smart contracts (2021)
- Overview of and interactions between smart contracts in blockchain and DLT systems (no date)

Furthermore, innovation methodologies, like hackathons, pilots, Kanban/scrum, 9 digital principles,²⁶ open science, and open data/software may help accelerate the adoption. Blockchain is believed to be an enabler in real-time reporting and verification models. This requires developing the next-generation sustainability monitoring protocols and standards. On a more speculative note, another association, Blockchain for Climate Foundation, is planning to put the entire Paris Agreement over the blockchain. Additionally, the foundation plans to create a global platform for national carbon accounts using blockchain technology, thereby enhancing transparency in monitoring national efforts towards environmental protection.

²⁴ See https://www.iof2020.eu

²⁵ See https://www.ledgerinsights.com/iso-blockchain-standards/

²⁶ See https://www.toladata.com/the-9-principles-for-digital-development/

The ongoing Covid-19 pandemic has created both challenges and opportunities for the application of blockchain and the developments are in favour of digital transformation in agriculture and its value chains. Measures to control virus outbreaks are disrupting global food supply chains. Border restrictions and lockdowns are slowing harvests, destroying livelihoods and hindering food transport. Fintech has proven to be instrumental for the recovery of food production in many countries. An example is how Agri-Wallet is teaming up with funding organizations to provide financial support to farmers in Kenya.²⁷

Data-driven solutions feature strongly in various response and recovery programmes of international organizations such as FAO's COVID-19 Response and Recovery Programmes and the World Economic Forum (WEF) toolkit.²⁸ It can be expected that these programmes and tools will further advance the development and adoption of blockchain applications for CCAM in agriculture.

²⁷ https://snv.org/update/snv-rabobank-ftma-and-agri-wallet-join-forces-ensuring-food-security-kenya-during-covid-19

²⁸ https://blockchain.news/analysis/world-economic-forum-wef-blockchain-toolkit-supply-chains-post-covid-19-economic-recovery

5 Conclusions and recommendations

5.1 Key features of blockchain that will help in tracking GHG emissions and offsets

Our study shows that blockchain is not a single technology, nor is blockchain a single entity. At its core, blockchain is a distributed ledger that is consensually shared, replicated and synchronized among different nodes. From the ecosystem perspective, blockchain is a governance technology for which rules and agreements need to be set and enforced. When widely adopted, BCT enables sharing information and building trust among people and organizations without resorting to a centralized system.

As explained in Section 3.1.2, the technical features of blockchain that will help in tracking GHG emissions and offsets are: 1) decentralization and consensus mechanisms to ensure immutability of records; 2) smart contracts to ensure automatic transactions; 3) redundancy and technical transparency to enable audit trail of permits, certifications and transactions. These features can also be used to track SDG indicators (especially those on SDG1, SDG5 and SDG13) relevant to climate change adaptation in agriculture.

The organizational feature of blockchain is the collaborative ecosystem that facilitates data sharing and fosters innovation and transformation.

5.2 Main areas of applications of blockchain in agriculture

As shown by the literature and the use cases, blockchain has been applied in different verticals (sectors) and horizontals (e.g., identity management, transactions and audit trail) in agriculture.

Currently, the main areas of application of blockchain for CCAM in agriculture are primarily rural financing and labour conditions in developing countries and quality assurance (organic, fairness, authenticity of premium products), automatic settlements (carbon credits) and traceability in developed countries.

Given the increasing attention for biodiversity and social-ecological resilience triggered by the ongoing Covid-19 pandemic, it is foreseeable that BCT will be proposed or used for monitoring the availability of food items (available stock and shortage), biodiversity, ecosystem services and gender-relevant SDG goals.

5.3 Key opportunities and challenges in applying blockchain for CCAM in agriculture

BCT can help improve transparency and accountability of CCAM activities and impacts in a wide range of verticals in agriculture. In supporting adaptation strategies, blockchain creates opportunities for new value chains and platforms for smallholder farmers through climate finance (rural credits through tokens, crowdfunding, crowd lending and microinsurance. It can also help in tracking the investment and outcomes of improved management practices for climate change adaptation. For climate change mitigation, the technology can lay the foundation for a global carbon data community that enables better monitoring and evaluation of climate change mitigation activities and supporting the development of carbon market. In the current state of digitalization and standardization, however, many challenges need to be overcome before the potential governance and business benefits can be brought to fruition (see Figure 7). The common challenges faced by all use cases are the complexity of the technology and the scalability of the application in different business ecosystems. Many challenges are however situational and context specific. Capacity development and standardization are key to addressing the complexity of the technology. For the latter, substantial coordination efforts are needed to clearly define the use case and bring key stakeholders on board.

As evidenced by the rising number of use cases in both developing and developed countries, there is a high level of awareness of the relevance of BCT to CCAM in agriculture. The enabling environments of these use cases commonly feature favourable national and international policies towards CCAM in agriculture and digital solutions. Ethereum is currently the most used blockchain framework in the use cases studied, mostly due to its ease of deployment for decentralized applications (DApps) and token-based transactions. Most use cases are currently funded by private companies or investors, with some through public private partnerships (PPP).

In the use cases studied, different types of farmers are participating in blockchain applications. Smallholder farmers are generally the end users and beneficiaries (better access to finance and global value chains). Professional farmers are sometimes initiators, project partners and operators of blockchain applications. Users of blockchain-based credit or insurance in climate finance are mainly smallholder farmers, although traders, banks and insurance companies also benefit from increased sales and market volume.

For initiators and operators of blockchain applications, the main challenge is how to acquire sufficient funding and technological resources for initial development and operations. Once the project is running, the major challenge is to attract investment and sufficiently large number of users for scaling up. For investors, the main challenge was the complexity and evolving nature of the technology which makes the success and return on investment uncertain. The complexity of the technology and lack of empirical evidence on the ground constitute a major challenge for public actors, non-profit private actors or impact investors to commit or invest in blockchain projects. For regulators and public sector actors, the challenge is how to set the regulatory framework and safeguards without impeding innovation.

5.4 Policy options

Blockchain represents a normative and governance technology that has implications for governance at various levels of societies. Our study on the opportunities and challenges in applying blockchain for CCAM shows that blockchain has great potential in the registration of identities and land titles in climate change adaptation and providing audit trail of emissions, carbon offsets, labelling and certification in climate change mitigation. This requires however a set of preconditions to be met before the application can be realized:

- enabling regulatory framework and safeguards;
- digitalization and datafication of carbon emissions and reductions of various CCAM measures;
- basic digital infrastructure (mobile networks and internet);
- digital literacy, affinity and capabilities of relevant actors, especially smallholder users and regulators.

Based on the state of play and outlook, three general policy options are possible for governments and public actors to guide and channel blockchain applications towards SDGs:

- establishing regulatory framework regarding the choice of blockchain frameworks and governance models
- coordinating and promoting standardization regarding the measurement and indicators of CCAM activities to be tracked by blockchain applications
- capacity development to improve the understanding and application of blockchain technology for CCAM activities for various stakeholders in blockchain ecosystems.

5.5 The role of blockchain applications for CCAM in agriculture

Given the current state of play and outlook, we foresee three lines of work for blockchain applications for CCAM in agriculture:

- establishing regulatory framework and safeguards for blockchain applications;
- standardization;
- capacity development.

5.5.1 Establishing regulatory framework and safeguards

It is commonly considered that blockchain offers a unique opportunity to improve transparency and accountability in agri-food chains and carbon markets. For the technology to reach its full potential—to be the game changer—it should be combined with enabling macro-economic policies and macro-prudential regulatory frameworks that can finance a multi-trillion-dollar transition (Chen, 2018). Furthermore, a list of safeguards should also be in place regarding land tenure, labour conditions (in particular the vulnerable groups such women and children), energy consumption and GHG emitted by the technology. This can go hand in hand with the work on further developing indicators for monitoring climate change impacts on gender inequality, ecosystem services, biodiversity for food and agriculture degradation and restoration (socio-ecological resilience) (FAO, 2019). In this regard, international policymakers can exert their influence to have indicators on these regards tracked by blockchain applications.

5.5.2 Standardization

As evidenced by the use cases, the rapid development of BCT has resulted in a large variety of blockchains in agriculture and related industries. Standardizing blockchain applications is important to increase interoperability, user protection, security, and uptake by businesses and other stakeholders. Several governments (e.g. Malta^{29 30} and China^{31 32}) have already developed standards which enable quality assurance. Global standards for blockchains should be developed. This includes standards regarding the design and performance of blockchain applications. These standards should address the risks of scams, incompatibility, security, user protection, electricity use, and illegal activities on blockchain platforms.

From the perspective of data input for blockchain applications, the standardization concerns the choice of indicators, methodologies and data standards regarding CCAM applications in agriculture. Institutions like FAO, ISO, ITU and other can develop, implement and promote international blockchain data standards, methodological guidelines and tools.

5.5.3 Capacity development

Climate change is one of the most complex issues facing us today as it involves many dimensions. There is a great need for professionals who can bridge the technical nitty-gritty of BCT and the bigger trends in society and policy in the context of climate change. Building and contributing to the knowledge base and databases of BCT for CCAM in agriculture can help in bridging this gap. Capacity development can also include facilitating knowledge dissemination through live or digital platforms and networks. For stakeholders in blockchain ecosystems, it is important to connect to or participate in

²⁹ Malta Digital Innovation Agency (2019). Retrieved from https://mdia.gov.mt/

³⁰ WH Partners (2019): Regulatory Framework in Malta for certification of blockchains and smart contracts. Retrieved from http://whpartners.eu/news/regulatory-framework-in-malta-for-certification-of-blockchains-and-smart-contracts

³¹ Kasetelein, R. (2019): Chinese government blockchain standardized certification received by lenovo, alipay and aelf. Medium. Retrieved from https://medium.com/@expathos/chinese-government-blockchain-standardized-certificationreceived-by-lenovo-alipay-and-aelf-3170dc26fe5

³² Standardization Administration of the P.R.C (2019). The State Standards Commission newly established a group of national professional standardization technical committees Retrieved from http://www.sac.gov.cn/xw/bzhdt/201911/t20191120_343876.htm

blockchain communities to share experiences and build alliances. The connection of currently fragmented blockchain ecosystems will facilitate global transformation of agri-food systems.

The UN, governments, farmers, traders and other stakeholders play a key role in the food system to move towards a climate resilient agriculture. The blockchain application for CCAM in agriculture needs support through related regional, national and local efforts through capacity-building, technology transfer, and knowledge-sharing work, as well as partnerships with other UN organizations such as the UNFCCC, ITU, UNDP, WFP, UNCEFACT and FAO. A network of rich databases can serve as 'oracle' for many blockchain applications in agriculture to (pre-)verify on-chain data and claims (Al-Breiki *et al.*, 2020). For example, FAO's Hand-in-Hand geospatial data platform³³ can be linked to blockchain ecosystems for CCAM in agriculture to address many problems related to the availability and quality of data as well as the verification of claims made on CCAM practices.

³³ See http://www.fao.org/hand-in-hand/en/

References and websites

References

- Adams, P.R., Frizzo-Barker, J., Ackah, B.B., Chow-White, P.A., 2019. Meetups: Making Space for Women on the Blockchain. In: Blockchain and Web 3.0: Social, Economic, and Technological Challenges. Routledge, pp. 48-61
- Adenle, A.A., Azadi, H., Arbiol, J., 2015. Global assessment of technological innovation for climate change adaptation and mitigation in developing world. Journal of environmental management 161, 261-275.

Al-Breiki, H., Rehman, M.H.U., Salah, K., Svetinovic, D., 2020. Trustworthy Blockchain Oracles: Review, Comparison, and Open Research Challenges. IEEE Access 8, 85675-85685.

- Amadu, F.O., McNamara, P.E., Miller, D.C., 2020. Understanding the adoption of climate-smart agriculture: A farm-level typology with empirical evidence from southern Malawi. *World Development* 126, 104692.
- Ante, L., 2020. Smart Contracts on the Blockchain–A Bibliometric Analysis and Review. Available at SSRN 3576393.
- Antonucci, F., Figorilli, S., Costa, C., Pallottino, F., Raso, L., Menesatti, P., 2019. A Review on blockchain applications in the agri-food sector. *Journal of the Science of Food and Agriculture* 99, 6129-6138.
- Atlam, H.F., Wills, G.B., 2019. Chapter One Technical aspects of blockchain and IoT, in: Kim, S., Deka, G.C., Zhang, P. (Eds.), *Advances in Computers*. Elsevier, pp. 1-39.
- Beck, R., Czepluch, J.S., Lollike, N., Malone, S., 2016. Blockchain-the Gateway to Trust-Free Cryptographic Transactions, ECIS, p. Research Paper 153.
- Birkenberg, A., Narjes, M.E., Reiser, B., Birner, R., 2020. The potential of carbon neutral labeling to engage coffee consumers in climate change mitigation. Journal of Cleaner Production, 123621.
- Bohme, R., Christin, N., Edelman, B., Moore, T., 2015. Bitcoin: Economics, Technology, and Governance. *J Econ Perspect* 29, 213-238.
- Bolt, J., 2019. Financial resilience of Kenyan smallholders affected by climate change, and the potential for blockchain technology. CCAFS.
- Buterin, V., 2015a. On Public and Private Blockchains, in: Buterin, V. (Ed.). Vitalik Buterin, Ethereum BLog (also available at https://blog.ethereum.org/2015/08/07/on-public-and-private-blockchains/)
- Buterin, V., 2015b. Visions, Part 1: The Value of Blockchain Technology, in: Buterin, V. (Ed.), 1 ed. Ethereum, Ethereum Blog.
- Chandra, A., McNamara, K.E., Dargusch, P., 2018. Climate-smart agriculture: perspectives and framings. Climate Policy 18, 526-541.
- Chen, D., 2018. Utility of the blockchain for climate mitigation. The Journal of The British Blockchain Association 1, 3577.
- Christidis, K., Devetsikiotis, M., 2016. Blockchains and Smart Contracts for the Internet of Things. Ieee Access 4, 2292-2303.
- Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., Maginnis, S., Maynard, S., Nelson, C.R., Renaud, F.G., 2019. Core principles for successfully implementing and upscaling Nature-based Solutions. Environmental Science & Policy 98, 20-29.
- Craig, T., Campbell, D., 2012. Organisations and the business environment. Routledge.
- Crumpler, K., Alexandre, M., Federici, S., Salvatore, M., Damen, B., Dasgupta, S., Wolf, J., Bernoux, M., 2019. Assessing the Role of Agriculture and Land Use in Nationally Determined Contributions: A Methodology. http://www.fao.org/3/CA5543EN/CA5543EN.pdf.
- Daniel, D., Ifejika Speranza, C., 2020. The Role of Blockchain in Documenting Land Users' Rights: The Canonical Case of Farmers in the Vernacular Land Market. Frontiers in blockchain 3, 19.
- Davidson, S., De Filippi, P., Potts, J., 2018. Blockchains and the economic institutions of capitalism. Journal of Institutional Economics, 1-20.
- De Vries, A., 2018. Bitcoin's growing energy problem. Joule 2, 801-805.

Donatti, C.I., Harvey, C.A., Martinez-Rodriguez, M.R., Vignola, R., Rodriguez, C.M., 2019. Vulnerability of smallholder farmers to climate change in Central America and Mexico: current knowledge and research gaps. Climate and Development 11, 264-286.

Drescher, D., 2017. Blockchain Basics, 1 ed. Apress, Frankfurt am Main, Germany.

- Drummer, D., Neumann, D., 2020. Is code law? Current legal and technical adoption issues and remedies for blockchain-enabled smart contracts. Journal of Information Technology, 0268396220924669.
- Ellebrecht, A., 2019. Chain of Custody and Transparency in Global Supply Chains, Sustainable Global Value Chains. Springer, pp. 227-237.
- Engel, S., Muller, A., 2016. Payments for environmental services to promote "climate-smart agriculture"? Potential and challenges. Agricultural Economics (United Kingdom) 47, 173-184.
- FAO, 2017. Tracking adaptation in agricultural sectors: Climate Change Adaptation Indicators. FAO, Rome.
- FAO, 2019. The State of World's Biodiversity for Food and Agriculture http://www.fao.org/state-ofbiodiversity-for-food-agriculture/en/.
- FAO, 2020a. Carbon footprint of the banana supply chain, http://www.fao.org/world-bananaforum/projects/good-practices/carbon-footprint/en/.
- FAO, 2020b. Climate-smart Agriculture Sourcebook, FAO, 2020 (http://www.fao.org/3/i3325e/i3325e08.pdf) (http://www.fao.org/climate-smart-agriculturesourcebook/production-resources/module-b2-livestock/chapter-b2-4/en/).
- Fellmann, T., Witzke, P., Weiss, F., Van Doorslaer, B., Drabik, D., Huck, I., Salputra, G., Jansson, T., Leip, A., 2018. Major challenges of integrating agriculture into climate change mitigation policy frameworks. Mitigation and Adaptation Strategies for Global Change 23, 451-468.
- Feng, Q., 2012. Addressing organic agricultural development in climate change mitigation and adaptation in China, pp. 3322-3325.
- Fenton, A., Paavola, J., Tallontire, A., 2015. Microfinance and climate change adaptation: an overview of the current literature. Enterprise development and microfinance 26, 262-273.
- Fuessler, J., León, F., Mock, R., Hewlett, O., Retamal, C., Thioye, M., Beglinger, N., Braden, S., Hübner, C., Verles, M., 2018. Navigating blockchain and climate action. Climate Ledger Initiative.
- Ganne, E., 2018. Can Blockchain revolutionize international trade? World Trade Organization, https://www.wto.org/english/res_e/booksp_e/blockchainrev18_e.pdf.
- Ge, L., Brewster, C., Spek, J., Smeenk, A., Top, J., Diepen, F.v., Klaase, B., Graumans, C., Ruyter de Wildt, M.d., 2017. Blockchain for agriculture and food: findings from the pilot study. Wageningen Economic Research, Wageningen.
- Godfray, H.C.J., Garnett, T., 2014. Food security and sustainable intensification. Philosophical transactions of the Royal Society B: biological sciences 369, 20120273.
- Gramoli, V., 2016. On the danger of private blockchains, Workshop on Distributed Cryptocurrencies and Consensus Ledgers (DCCL'16).
- Gujral, P., 2019. What ecosystems are in blockchains? Blog: https://www.snowball.money/post/whatecosystems-are-in-blockchains.
- Hartmann, S., Thomas, S., 2020. Applying blockchain to the Australian carbon market. Economic Papers: A journal of applied economics and policy 39, 133-151.
- Havlík, P., Valin, H., Gusti, M., Schmid, E., Leclère, D., Forsell, N., Herrero, M., Khabarov, N.,Mosnier, A., Cantele, M., 2015. Climate change impacts and mitigation in the developing world: an integrated assessment of the agriculture and forestry sectors. The World Bank.

Howson, P., 2019. Tackling climate change with blockchain. Nature Climate Change 9, 644-645.

- Howson, P., 2020. Building trust and equity in marine conservation and fisheries supply chain management with blockchain. Marine Policy, 103873.
- Hughes, K., 2017. Blockchain, the greater good, and human and civil rights. Metaphilosophy 48, 654-665.
- Hussain, A., Sarangi, G.K., Pandit, A., Ishaq, S., Mamnun, N., Ahmad, B., Jamil, M.K., 2019.
 Hydropower development in the Hindu Kush Himalayan region: Issues, policies and opportunities.
 Renewable and Sustainable Energy Reviews 107, 446-461.
- Iansiti, M., Lakhani, K.R., 2017. The Truth About Blockchain. Havard Business Review January-February, 118-127.
- IBM, 2016. Making Blockchain Real for Business. IBM.

- IPCC, 2019. IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems. https://www.ipcc.ch/site/assets/uploads/2019/08/4.-SPM_Approved_Microsite_FINAL.pdf.
- ITU-T, 2019. ITU-T Technical Specification FG DLT D3.1 Distributed ledger technology reference architecture. https://www.itu.int/en/ITU-T/focusgroups/dlt/Pages/default.aspx.
- Jim Brill, D., Jerry Cuomo, Ramesh Gopinath, Peter Korsten, Brigid McDermott, John McLean, Veena Pureswaran, Shanker Ramamurthy, Wallis., J., 2016. Fast forward rethinking enterprises, ecosystem and economies with blockchains. IBM Institute for Business Value.
- Kamath, R., 2018. Blockchain for Women Next Generation for Sustainable Development Goal 5. Journal of Poverty Alleviation & International Development 9.
- Kamilaris, A., Fonts, A., Prenafeta-Boldu, F.X., 2019. The rise of blockchain technology in agriculture and food supply chains. Trends in Food Science & Technology 91, 640-652.
- Kim, S.-K., Huh, J.-H., 2020. Blockchain of Carbon Trading for UN Sustainable Development Goals. Sustainability 12, 4021.
- Kosba, A., Miller, A., Shi, E., Wen, Z., Papamanthou, C., 2016. Hawk: The blockchain model of cryptography and privacy-preserving smart contracts, Security and Privacy (SP), 2016 IEEE Symposium on. Institute of Electrical and Electronics Engineers, pp. 839-858.
- Kouhizadeh, M., Sarkis, J., 2018. Blockchain practices, potentials, and perspectives in greening supply chains. Sustainability 10, 3652.
- Krause, M.J., Tolaymat, T., 2018. Quantification of energy and carbon costs for mining cryptocurrencies. Nature Sustainability 1, 711-718.
- Kumar, A., Fischer, C., Tople, S., Saxena, P., 2017. A Traceability Analysis of Monero's Blockchain. IACR Cryptology ePrint Archive 2017, 338.
- Lake, I.R., Hooper, L., Abdelhamid, A., Bentham, G., Boxall, A.B.A., Draper, A., Fairweather-Tait, S.,
 Hulme, M., Hunter, P.R., Nichols, G., Waldron, K.W., 2012. Climate change and food security:
 Health impacts in developed countries. Environmental Health Perspectives 120, 1520-1526.
- Lin, Y.-P., Petway, J.R., Anthony, J., Mukhtar, H., Liao, S.-W., Chou, C.-F., Ho, Y.-F., 2017. Blockchain: The evolutionary next step for ICT e-agriculture. Environments 4, 50.
- Linnerooth-Bayer, J., Hochrainer-Stigler, S., 2015. Financial instruments for disaster risk management and climate change adaptation. Climatic Change 133, 85-100.
- Locatelli, B., Catterall, C.P., Imbach, P., Kumar, C., Lasco, R., Marín-Spiotta, E., Mercer, B., Powers, J.S., Schwartz, N., Uriarte, M., 2015. Tropical reforestation and climate change: beyond carbon. Restoration Ecology 23, 337-343.
- Louise Lemieux, V., 2015. Trusting Records: Is Blockchain Technology the Answer?
- Lovell, H.C., 2010. Governing the carbon offset market. Wiley interdisciplinary reviews: climate change 1, 353-362.
- Lutz, W., Striessnig, E., 2015. Demographic aspects of climate change mitigation and adaptation. Population Studies 69, S69-S76.
- Mackey, B., Prentice, I.C., Steffen, W., House, J.I., Lindenmayer, D., Keith, H., Berry, S., 2013. Untangling the confusion around land carbon science and climate change mitigation policy. Nature Climate Change 3, 552-557.
- Mainelli, M., Smith, M., 2015. Sharing ledgers for sharing economies: an exploration of mutual distributed ledgers (aka blockchain technology). The Journal of Financial Perspectives 3, 38-69.
- Malik, S., Singh, A., Kumari, R., Pathak, S., Rohila, S., Choki, S., Pandey, B., Leveraging the potential of agriculture sector and food supply with block chain technology-A review.
- Masanet, E., Shehabi, A., Lei, N., Vranken, H., Koomey, J., Malmodin, J., 2019. Implausible projections overestimate near-term Bitcoin CO2 emissions. *Nature Climate Change* 9, 653–654.
- Mata Dona, J.R., 2019. Stockholm convention on the use of blockchain to boost climate action. *Journal of International Arbitration* 36, 161-170.
- Mora, C., Rollins, R.L., Taladay, K., Kantar, M.B., Chock, M.K., Shimada, M., Franklin, E.C., 2018. Bitcoin emissions alone could push global warming above 2°C.
- Motta, G.A., Tekinerdogan, B., Athanasiadis, I.N., 2020. Blockchain Applications in the Agri-Food Domain: The First Wave. *Frontiers in Blockchain* 3, 6.
- Muller, A., 2012. Agricultural land management, carbon reductions and climate policy for agriculture. *Carbon Management* 3, 641-654.
- Nakamoto, S., 2008a. Bitcoin: A peer-to-peer electronic cash system.
- Nakamoto, S., 2008b. Bitcoin: A Peer-to-Peer Electronic Cash System. www.bitcoin.org.

- Niranjanamurthy, M., Nithya, B., Jagannatha, S., 2018. Analysis of Blockchain technology: pros, cons and SWOT. Cluster Computing, 1-15.
- Ølnes, S., 2016. Beyond Bitcoin Enabling Smart Government Using Blockchain Technology, in: Scholl, H.J., Glassey, O., Janssen, M., Klievink, B., Lindgren, I., Parycek, P., Tambouris, E., Wimmer, M.A., Janowski, T., Sá Soares, D. (Eds.), Electronic Government. Springer International Publishing, Cham, pp. 253-264.
- Pan, Y., Zhang, X., Wang, Y., Yan, J., Zhou, S., Li, G., Bao, J., 2019. Application of Blockchain in Carbon Trading. Energy Procedia 158, 4286-4291.
- Reijers, W., O'Brolcháin, F., Haynes, P., 2016. Governance in Blockchain Technologies & Social Contract Theories. Ledger 1, 134-151.
- Riasanow, T., Burckhardt, F., Soto Setzke, D., Böhm, M., Krcmar, H., 2018. The Generic Blockchain Ecosystem and its Strategic Implications.
- Rosenstock, T.S., Lamanna, C., Chesterman, S., Bell, P., Arslan, A., Richards, M., Rioux, J., Akinleye, A., Champalle, C., Cheng, Z., 2016. The scientific basis of climate-smart agriculture: A systematic review protocol.
- Roundy, P.T., 2019. Regional differences in impact investment: A theory of impact investing ecosystems. Social Responsibility Journal.
- Ruben, R., Wattel, C., Van Asseldonk, M., 2018. Rural Finance to Support Climate Change Adaptation: Experiences, Lessons and Policy Perspectives. The Climate-Smart Agriculture Papers, 301.
- Sayeed, S., Marco-Gisbert, H., 2019. Assessing blockchain consensus and security mechanisms against the 51% attack. Applied Sciences 9, 1788.
- Schellekens, M., Tai, E.T.T., Kaufmann, W., Schemkes, F., Leenes, R., 2019. Blockchain en het recht. Universiteit van Tilburg-Tilburg Institute for Law, Technology, and Society
- Scherr, S.J., Sthapit, S., 2009. Mitigating climate change through food and land use. Worldwatch Paper, 1-49.
- SedImeir, J., Buhl, H.U., Fridgen, G., Keller, R., 2020. The Energy Consumption of Blockchain Technology: Beyond Myth. Business and Information Systems Engineering.
- Senou, R.B., Dégila, J., Adjobo, E.C., Djossou, A.P.M., 2019. Blockchain for Child Labour Decrease in Cocoa Production in West and Central Africa. IFAC-PapersOnLine 52, 2710-2715.
- Sharma, S., 2017. Climate change and blockchain. Available at SSRN 3088990.
- Smith, P., Soussana, J.F., Angers, D., Schipper, L., Chenu, C., Rasse, D.P., Batjes, N.H., van Egmond, F., McNeill, S., Kuhnert, M., Arias-Navarro, C., Olesen, J.E., Chirinda, N., Fornara, D., Wollenberg, E., Álvaro-Fuentes, J., Sanz-Cobena, A., Klumpp, K., 2020. How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. Global Change Biology 26, 219-241.
- Sova, C.A., Grosjean, G., Baedeker, T., Nguyen, T.N., Wallner, M., Nowak, A., Corner-Dolloff, C., Girvetz, E., Laderach, P., Lizarazo, M., 2018. Bringing the Concept of Climate-Smart Agriculture to Life: Insights from CSA Country Profiles Across Africa, Asia, and Latin America. World Bank.
- Stoll, C., Klaaßen, L., Gallersdörfer, U., 2019. The Carbon Footprint of Bitcoin. Joule 3, 1647-1661.
- Swan, M., 2016. Blockchain Temporality: Smart Contract Time Specifiability with Blocktime, in: Alferes, J.J., Bertossi, L., Governatori, G., Fodor, P., Roman, D. (Eds.), Rule Technologies. Research, Tools, and Applications. Springer, Cham, pp. 184-196.
- Swanson, T., 2015. Consensus-as-a-service: a brief report on the emergence of permissioned, distributed ledger systems. Report, available online, Apr.
- Sylvester, G., 2019. E-agriculture in Action: Blockchain for Agriculture: Opportunities and Challenges. International Telecommunication Union.
- Thomason, J., Ahmad, M., Bronder, P., Hoyt, E., Pocock, S., Bouteloupe, J., Donaghy, K., Huysman, D., Willenberg, T., Joakim, B., 2018. Blockchain—powering and empowering the poor in developing countries, Transforming climate finance and green investment with blockchains. Elsevier, pp. 137-152.
- Thomson, A.M., Ellis, E.C., Grau, H.R., Kuemmerle, T., Meyfroidt, P., Ramankutty, N., Zeleke, G., 2019. Sustainable intensification in land systems: trade-offs, scales, and contexts. *Current Opinion in Environmental Sustainability* 38, 37-43.
- Thornton, P.K., Kristjanson, P., Förch, W., Barahona, C., Cramer, L., Pradhan, S., 2018. Is agricultural adaptation to global change in lower-income countries on track to meet the future food production challenge? Global Environmental Change 52, 37-48.

- Tian, F., 2016. An agri-food supply chain traceability system for China based on RFID & blockchain technology, Service Systems and Service Management (ICSSSM), 2016 13th International Conference on. Institute of Electrical and Electronics Engineers, pp. 1-6.
- Trendov, N.M., Varas, S., Zeng, M., 2019. Digital Technologies in Agriculture and Rural Areas. FAO: Rome, Licence: cc by-nc-sa 3.0 igo. http://www.fao.org/3/ca4887en/ca4887en.pdf.
- Tripoli, M., Schmidhuber, J., 2018. Emerging Opportunities for the Application of Blockchain in the Agri-food Industry. FAO and ICTSD: Rome and Geneva. Licence: CC BY-NC-SA 3.
- Tschora, H., Cherubini, F., 2020. Co-benefits and trade-offs of agroforestry for climate change mitigation and other sustainability goals in West Africa. *Global Ecology and Conservation* 22.
- van Pelt, R., Jansen, S., Baars, D., Overbeek, S., 2020. Defining Blockchain Governance: A Framework for Analysis and Comparison. *Information Systems Management*, 1-21.
- Vos, J., 2017. Blockchain-based land registry: panacea, illusion or something in between, IPRA/CINDER Congress, Dubai. European Land Registry Association (ELRA).
- Vranken, H., 2017. Sustainability of bitcoin and blockchains. *Current Opinion in Environmental* Sustainability 28, 1-9.
- Walport, M., 2016. Distributed ledger technology: beyond block chain. UK Government Office for Science.
- Wang, W., Hoang, D.T., Hu, P., Xiong, Z., Niyato, D., Wang, P., Wen, Y., Kim, D.I., 2019. A survey on consensus mechanisms and mining strategy management in blockchain networks. IEEE Access 7, 22328-22370.
- Wiebe, K., Robinson, S., Cattaneo, A., 2019. Climate change, agriculture and food security: impacts and the potential for adaptation and mitigation, *Sustainable Food and Agriculture*. Elsevier, pp. 55-74.
- Wilshaw, R., 2018. UK Supermarket Supply Chains: Ending the human suffering behind our food.
- Wright, A., De Filippi, P., 2015. Decentralized blockchain technology and the rise of lex cryptographia. Social Science Research Network.

Yermack, D., 2017. Corporate Governance and Blockchains. Review of Finance 21, 7-31.

Zougmoré, R., Partey, S., Ouédraogo, M., Omitoyin, B., Thomas, T., Ayantunde, A., Ericksen, P., Said, M., Jalloh, A., 2016. Toward climate-smart agriculture in West Africa: a review of climate change impacts, adaptation strategies and policy developments for the livestock, fishery and crop production sectors. *Agriculture & Food Security* 5, 26.

Websites

Introduction to blockchain

https://cointelegraph.com/explained https://blockgeeks.com/guides/what-is-blockchain-technology/ https://www.wired.com/story/guide-blockchain/ https://www.geeksforgeeks.org/blockchain-technology-introduction/

Blockchain implementation guides and resources

https://medium.com/blockchain-at-berkeley/building-it-better-a-simple-guide-to-blockchain-usecases-de494a8f5b60 https://www.itransition.com/blog/blockchain-implementation-guide https://widgets.weforum.org/blockchaintoolkit/pdf/WEF_Redesigning_Trust_Blockchain_Deployment%20Toolkit.pdf https://www.ledgerinsights.com/

Blockchain performance benchmark framework

https://www.allerin.com/blog/alternatives-to-blockchain-that-businesses-must-consider https://github.com/TrustedBlockchain/TrustedBench https://blockchainconsultants.io/about-us/ https://hackernoon.com/how-to-choose-a-consensus-algorithm-for-blockchain-backed-services-6d3ece7fa56 https://rubygarage.org/blog/best-blockchain-frameworks

Blockchain use cases in agriculture

https://www.itu.int/dms_pub/itu-d/opb/str/D-STR-E_AGRICULT.03-2018-PDF-E.pdf https://www.eublockchainforum.eu/initiative-map https://www.blockdata.tech/Researchers/ https://www.disruptordaily.com/blockchain-use-cases-agriculture/ https://breakermag.com/73-blockchain-social-good-organizations-that-are-actually-doing-something/ https://breakermag.com/73-blockchain-social-good-organizations-that-are-actually-doing-something/ https://www.cta.int/en/blockchain https://climateledger.org/en/About.12.html https://medium.com/swlh/blockchain-for-agriculture-5b0a0baa0aa3 https://www.intellias.com/how-to-apply-the-blockchain-to-agricultural-supply-chains-while-avoidingembarrassing-mistakes/

General guidelines to digital development

https://digitalprinciples.org/

Appendix 1 Long list of use cases

(Detailed information can be found in Excel sheet)

Case study name	Final choice	Found by whom	Short list? Y / N	Suitable Use Case (notes)?	Region	Agrifood sector	Year of establishment	Adaptation / mitigation	Information / source (web)
AgriDigital		Lan	Y	Multinumose digital trust	Australia	Grain crons	2015	Adaptation	https://www.agridigital.io/products/blockchaip:
- Ingrital		Lun		less relevant to climate	rastrana	orally crops	2015	nauptation	http://www.djrugtanto/products/products/products/
				change					https://www.disruptordally.com/blockcnalit-lit-
					107.01.11		0.017		agriculture-use-case-agridigital/
Agriledger		Lan	N	Mainly on efficiency, payment and traceability, less on	UK/Haiti	Food and cash crops	2017	Adaptation	http://www.agriledger.io/
Adlibity		Lan	N	Earmers' identity navment	Australia, Indonesia	Crone	2017	Adaptation	https://www.assuite.assu/
Agointy		Ldii	IN .	ranners identity, payment	Papua New Guinea, Ethionia	crops	2017	Adaptation	https://www.agunity.com/
Ambrosus		Lan	N	Focus on traceability	Switzerland/France	Olive oil	2017	Adaptation	https://ambrosus.com/
Beefchain		Lan	Y	Agriculture, livestock	US, Kenya	Livestock	2018	Adaptation	https://beefchain.com/
Beefledger		Lan	N	Farly phase, similar to	Australia	Livestock	2019	Adaptation	https://beefledger.io/
Beyt360		Lan	N	Beefchain focus on traceability and	US/Global	All sectors	2016	Adaptation	https://www.bext260.com/
Carbon Cocknit		Lan	N	payment	Cuitzerland	Non specific	2013	Adaptation	
сагоон соскріс		Ldii	IN .	carly priase, carbon tracking	Switzenand	Non specific	2017	Adaptation	case-4.46.html
CarbonX		Lan	N	Carbon trading	Canada	Forestry	2018	Mitigation	https://www.carbonx.ca/
Clean Coin		Lan	N	Farm removed from	Switzerland	Non specific	2017	Adaptation	http://www.cleancoins.io/files/cleancoin/factsheet.pdf
				agriculture, related to Bitcoin and Ethereum					
Climatecoin		Lan	N	Platform for carbon offsetting	Switzerland	Non specific	2014	Adaptation	https://climatetrade.com/
Earth Token		Lan	N	Comprehensive climate change adaptation strategies	Global (Isle of Man)	Non specific	2017	Adaptation/Migitation	https://earth-token.com/
Fishcoin		Lan	N	Focus on fish catch	Sigapore	Fishery	2018	Adaptation	https://fishcoin.co/
Ixo Blockchain		Lan	N	Focus on impact accounting,	Switzerland	Non specific	2007/2018	Adaptation/Migitation	https://www.climateledger.org/en/Use-
Nori		Lan	Y	Carbon sequestration farmer	us	Arable farming	2017	Adaptation/Migitation	https://pori.com/:
		Con		carbon sequestion, farmer	00	Audole furning	2017	, addptation, ingration	https://www.crunchbase.com/organization/nor
Redd-Chain Project		Lan	N	Carbon accounting, deforestation	Switzerland	Forestry	2017	Mitigation	https://www.climateledger.org/en/Use- Cases.33.html
SELBER		Lan	N	Mainly focussed on energy	Switzerland	Non specific	2019	Adaptation	https://www.climateledger.org/en/News/Archi ve.35.html
Shamba Records		Lan	N	Less focus on climate change	Kenva	Non specific	2019	Adaptation	https://shambarecords.co.ke/
Treecoin		Lan	Y	Carbon sequestration	Switzerland	Forestry	2019	Mitigation	https://tree-coin.io/
VE-Chain		Lan	N	Traceability and authenticity	APAC, ASEAN	Non specific	2017	Adaptation	https://www.vechain.com/
Veridium		Lan	N	Carbon credit, less agri	Hongkong	Non specific	2018	Adaptation	https://www.veridium.io/
SunExhange		Marcel	N	Unclear the extend farmers have access	Africa	Non specific	2015	Mitigation	https://thesunexchange.com/
Crop insurance India		Marcel	N	Limited information	India	Non specific	Unclear	Adaptation	https://edepot.wur.nl/472583
Crop insurance Kenya		Marcel	N	Testing phase	Kenya	Non specific	Test	Adaptation	https://www.climatefinancelab.org/project/climate- risk-crop-insurance/
Smart(ron (incurance)		Marcel	N	Limited information	China	Non specific	Unclear	Adaptation	https://odopot.www.pl/473592
Agri-		Lan	v	Depending on outreach and	Kenya	Cash grone	2017	Adaptation	https://agri.wallot.com/:
wallet/Coin22/FARMS		Lun		information on blockchain	liciju		2017	haptation	https://fairfood.nl/en/blockchain-for-agrifood/case- study-agri-wallet/
Crop insurance Sri		Marcel	Y	200 farmers in 2019 and	Sri Lanka	Arable farming	2019	Adaptation	https://aon.mediaroom.com/2019-07-01-Aon-Oxfam-
Lanka				10,000 in 2020, Collaboration					and-Etherise-Jaunch-first-blockchain-based-agricultural-
				by Oxfam, Sanasa, Aon, and					incurance policies for smallholder formers in Sri
				Etherisc.					Laska2erene energy ND 00 2010 00 10 Marketer
				Etherisc					agri-ins&promo position=NR-08
EthicHub (crowd		Marcel	Y	Crowd lending is unlocks	Mexico (Africa?)	Non specific	2018	Adaptation	https://medium.com/ethichub
Agroplexi (credit)		Marcel	N		Nigeria (scaling to the Caribbean)	Non specific			https://agroplexi.com/
Binkabi (credit)		Marcel	N	Several international banks	Nigeria and Vietnam		2017	Adaptation	https://www.binkabi.io/
billkabi (credit)		harcer	N	involved	(expanding to South Africa and East Africa)		2017	Adaptation	Tecos, / www.binkeb.co/
Land LavBv		Marcel	Y	Land, finance	Kenva, Ghana	Non specific	2017	Adaptation	https://brbe.io/
Pure Grow		Marcel	N	Transparency, pilot	Uganda	Crops	2018	Adaptation	inclusion in decide
Poseidon		Mireille	Y	Carbon credit trading AT	Global	Agroforesty	2018	Adaptation/Migitation	https://poseidon.eco/
- OSCIDENT		, in calle		reforestation		ngrotoresty	2010	nauptation nigitation	https://blog.usejournal.com/putting-the-paris- agreement-on-the-blockchain-57eda4c481af

Appendix 2 Shortlisted use cases

Overview of shortlisted use cases

Use case	Region	Year of	CCAM activities	Agrifood sector
		Establishment		
AgriDigital	Australia	2015	Adaptation, financing	Grain, crops
Agri-wallet	Kenya, Asia	2016	Adaptation, financing	Crops
Beefchain	US	2018	Mitigation, traceability	Livestock
EthicHub	Mexico, Africa	2017	Adaptation, finance	Non specific
Insurance	Sri Lanka	2017	Adaptation, finance	Paddy rice farming
Land LayBy	Kenya, Ghana	2018	Adaptation, finance	Non specific
Nori	US	2018	Adaptation & Mitigation, carbon	Arable farming
			market	
Poseidon	Global	2019	Adaptation/Mitigation	Agroforesty
Treecoin	Switzerland,	2018	Mitigation, carbon sequestration	Forestry
	Paraguay			

AgriDigital

General					
Title of use case	AgriDigital				
Website	https://www.agridigital.io/				
Sector and product	Arable farming, grains				
Status	Several Proof o	of Concepts (PoCs)	and pilots developed, ongoing new		
	projects				
Goal	Creating digital trust in agri-food chains				
max. 1-2 sentences					
Climate change adaptation or mitigation	Adaptation (climate finance)				
Key actors involved	Actor	Role (Initiator, funding, IT provider,			
			user, other)		
	AgriDigital	Private, start-up	Initiator, Operator		
	CBH Group	Private	Funding, User		
	Rabobank	Private	Funding, User		
	Fletcher	Private	User		
	International				
	Export				
Description					
Reason to start the project	- Piloting blockchain in grains supply chains				
	- Improving efficiency and trust in transactions				
	- Improving e	fficiency and trust i	n transactions		
Start date	- Improving e 2015	fficiency and trust i	n transactions		
Start date Preconditions	- Improving e 2015 - Inefficiencies	fficiency and trust i s in supply chain	n transactions		
Start date Preconditions assumed before starting	Improving e 2015 Inefficiencies Payment risk	fficiency and trust i s in supply chain ks for farmers	n transactions		
Start date Preconditions assumed before starting	 Improving et 2015 Inefficiencies Payment risk Start-up Agr 	fficiency and trust i s in supply chain <s farmers<br="" for="">iDigital working in</s>	n transactions the grains industry		
Start date Preconditions assumed before starting Introduction	 Improving et 2015 Inefficiencies Payment risk Start-up Agr Creating digital 	fficiency and trust i s in supply chain ks for farmers iDigital working in ital trust by improv	n transactions the grains industry ing efficiency, transparency and payment		
Start date Preconditions assumed before starting Introduction objectives, preparations	 Improving et 2015 Inefficiencies Payment risk Start-up Agr Creating digisettlement 	fficiency and trust i s in supply chain <s farmers<br="" for="">iDigital working in ital trust by improv</s>	n transactions the grains industry ing efficiency, transparency and payment		
Start date Preconditions assumed before starting Introduction objectives, preparations	 Improving el 2015 Inefficiencies Payment risk Start-up Agr Creating dig settlement Piloting block 	fficiency and trust i s in supply chain <s farmers<br="" for="">iDigital working in ital trust by improv <chain< th=""><th>n transactions the grains industry ing efficiency, transparency and payment</th></chain<></s>	n transactions the grains industry ing efficiency, transparency and payment		
Start date Preconditions assumed before starting Introduction objectives, preparations Procedure	 Improving et 2015 Inefficiencies Payment risk Start-up Agr Creating digisettlement Piloting block Developing p 	fficiency and trust i s in supply chain ks for farmers iDigital working in ital trust by improv kchain platform and blocke	n transactions the grains industry ing efficiency, transparency and payment chain protocol		
Start date Preconditions assumed before starting Introduction objectives, preparations Procedure which steps were taken	 Improving et 2015 Inefficiencies Payment risk Start-up Agr Creating digisettlement Piloting block Developing p Finding laure 	fficiency and trust i s in supply chain ks for farmers iDigital working in ital trust by improv kchain platform and blockd ching user	n transactions the grains industry ing efficiency, transparency and payment chain protocol		
Start date Preconditions assumed before starting Introduction objectives, preparations Procedure which steps were taken	 Improving ei 2015 Inefficiencies Payment risk Start-up Agr Creating digisettlement Piloting block Developing p Finding laund Partnering w 	fficiency and trust i s in supply chain s for farmers iDigital working in ital trust by improv kchain blatform and blocko ching user ith CBH group	n transactions the grains industry ing efficiency, transparency and payment chain protocol		
Start date Preconditions assumed before starting Introduction objectives, preparations Procedure which steps were taken Results	 Improving el 2015 Inefficiencies Payment risk Start-up Agr Creating dig settlement Piloting block Developing p Finding laum Partnering w Automatic sett 	fficiency and trust i s in supply chain s for farmers iDigital working in ital trust by improv kchain blatform and blocko ching user ith CBH group lement of payment	n transactions the grains industry ing efficiency, transparency and payment thain protocol		
Start date Preconditions assumed before starting Introduction objectives, preparations Procedure which steps were taken Results or success scenario	 Improving el 2015 Inefficiencies Payment risk Start-up Agr Creating digisettlement Piloting block Developing p Finding launa Partnering w Automatic sett Farmers in 3 	fficiency and trust i s in supply chain s for farmers iDigital working in ital trust by improv kchain olatform and blockd ching user with CBH group lement of payment s countries	n transactions the grains industry ing efficiency, transparency and payment chain protocol to farmers via smart contract:		
Start date Preconditions assumed before starting Introduction objectives, preparations Procedure which steps were taken Results or success scenario when still in progress	 Improving ei 2015 Inefficiencies Payment risk Start-up Agr Creating digi settlement Piloting block Developing p Finding launa Partnering w Automatic sett Farmers in 3 Two buyers' 	fficiency and trust i s in supply chain s for farmers iDigital working in ital trust by improv kchain blatform and block ching user with CBH group lement of payment countries groups	n transactions the grains industry ing efficiency, transparency and payment thain protocol to farmers via smart contract:		
Start date Preconditions assumed before starting Introduction objectives, preparations Procedure which steps were taken Results or success scenario when still in progress Conclusions	 Improving et 2015 Inefficiencies Payment risk Start-up Agr Creating digisettlement Piloting block Developing p Finding laune Partnering w Automatic settt Farmers in 3 Two buyers' 	fficiency and trust i s in supply chain ks for farmers iDigital working in ital trust by improv kchain blatform and blockd ching user ith CBH group lement of payment countries groups nt terms and trans	n transactions the grains industry ing efficiency, transparency and payment thain protocol to farmers via smart contract: actional transparency for farmers is		

Follow-up activities	Developing new use cases in other countries
Organizational	
Potential business benefits from	Efficiency, speed of payment (shorter terms) and payment security
blockchain use	
Potential governance benefits from	Less fraud, more transparency, removal of counterparty risk for sellers by
blockchain use	real-time payment; automating and democratising access to supply chain
	finance for buyers.
Special concerns	Privacy of transactional data
political, environmental, social, technical,	
economic, legal, etc.	
Technical features	
Used blockchain framework	Ethereum based Smart Contract and tokens
incl. short motivation for this choice	
Type of blockchain (public, private,	Private
hybrid)	
Type of consensus algorithm used	Raft consensus mechanism
Use of smart contract	Yes, with Protocol: Geora
Use of tokens	Agricoin
Use of any special hardware or	IoT, sensor
techniques	
e.g. IoT, QR, RFID, LoRa, etc.	
Connection with existing	N/A
databases/systems/ERPs	
Open-source software being	Proprietary
used/proposed	
Links to related information	https://www.agridigital.io/reports/blockchain-pilot-report
incl. technical white papers	https://www.disruptordaily.com/blockchain-in-agriculture-use-case-
	agridigital/
	https://medium.com/lokaal/12-blockchain-food-agriculture-companies-in-
	their-own-words-71f8398252eb
	https://events.development.asia/system/files/materials/2019/10/201910-
	geora.pdf
	https://development.asia/explainer/transforming-agricultural-supply-
	chains-using-blockchain

Agri-Wallet

General							
Title of use case	Agri-Wallet						
Website	https://agri-wallet.com/						
Sector and product	Cash crops, finance and payment services						
Status	Ongoing						
Goal	Improving sma	allholder farmers' a	ccess to finance and high-quality inputs				
max. 1-2 sentences							
Climate change adaptation or mitigation	Adaptation						
Key actors involved	Actor Public/Private Role (Initiator, funding, IT provider,						
			user, other)				
	Dodore	Private, start-up	Initiator, Operator				
	Coin22	Private	IT provider, partner				
	Rabobank	Private	Funding/Loan				
	Farmers	Private	User				
	Agro-shops	Private	User				
	Mastercard	Private	Funding/Donor				
	Foundation		_				
	IDH Farmfit	Public	Funding/Donor				
	fund		_				
	FMO	Private	Funding/Donor				
	World Bank	Public	Funding/Award/Grant				
Description	I		<u> </u>				
Reason to start the project	Smallholder far	rmers in Kenva ofte	en lack access to financial services and				
······	inputs due to in	rregular cash flows					
Start date	2017						
Preconditions	- Farmers hav	e access to mobile	networks and mobile digital wallet				
assumed before starting	developed w	ith M-Pesa					
	- Loan provide	ers and merchants	(input suppliers) accept tokens for				
	purchases ar	nd payments and s	aving				
	- Tokens are e	earmarked for input	ts (seed and fertilizer)				
Introduction	- Agri-Wallet o	contributes to effici	ent and reliable agri-finance for farmers				
objectives, preparations	with irregula	r cash flows					
	- Farmers are	provided with a fre	ee business account that can be used to				
	purchase, se	ell and save					
	- Payments ca	n be in M-Pesa or 1	tokens				
	- Rabobank pr	ovides short-term	loans though Agri-Wallet with limited				
	paper work						
Procedure	- Developing r	nobile payment sys	stem				
which steps were taken	- Onboarding	of farmers, supplie	rs and other merchants				
	- Publicity thro	ough awards and of	ther prizes				
Results	- Value propos	sition well received	in the market, reaching >25 000 farmers				
or success scenario	in Kenya, pa	rtnered with more	than 50 buyers and 100 input suppliers				
when still in progress	- Won multiple	e awards					
Conclusions							
Follow-up activities	- Scaling up						
	- Developing r	new use cases in ot	her countries				
	- Partnership	with IDH Farmfit Fu	and and FMO				
Organizational							
Potential business benefits from	- Improved ac	cess to finance for	farmers with less transaction costs and				
blockchain use	paper work						
	- Improved pr	oductivity due to b	etter access to high quality inputs (seed,				
	fertilizer etc.	.)					
Potential governance benefits from	- More transpa	arency					
blockchain use	- less (default) risk					
	- Inclusivenes	s (low income, wor	nen, youth)				
Special concerns	Helping the vul	Inerable people (lov	w income, women, youth) in developing				
political, environmental, social, technical,	countries						
economic, legal, etc.							

Technical features	
Used blockchain framework	Ethereum, enabling smart contracts and the use of tokens
incl. short motivation for this choice	
Type of blockchain (public, private,	Public/private
hybrid)	
Type of consensus algorithm used	Proof of Work
Use of smart contract	Yes
Use of tokens	Yes, through Coin22
Use of any special hardware or	Not yet
techniques	
e.g. IoT, QR, RFID, LoRa, etc.	
Connection with existing	Connected to mobile payment system M-Pesa
databases/systems/ERPs	
Open-source software being	Proprietary
used/proposed	
Links to related information	https://www.cta.int/en/digitalisation/all/article/agri-wallet-a-wallet-for-
incl. technical white papers	smallholder-farmers-sid00f60f624-f62a-4b58-bd27-bd2c838b724f
	https://www.raflearning.org/post/understanding-ag-fintechs-business-
	models-agri-wallet-case-study

Beefchain

General						
Title of use case	Beefchain					
Website	https://beefchair	n.com				
Sector and product	Agriculture, livestock					
Status	Unknown					
Goal	BeefChain's RFID tags and other IoT devices upload unique cow/calf					
max. 1-2 sentences	information to th	e blockchain to est	tablish immutable, auditable			
	provenance to be	etter capture the fr	ee range, grass-fed premium.			
Climate change adaptation or mitigation	Mitigation					
Key actors involved	Actor	Public/Private	Role (initiator, funding, tech, other)			
	BeefChain	Private	Blockchain start-up, initiator (Wyoming			
	Deerenan	linute	Certified Beef)			
	Avery Dennison	Private	Packaging materials solution company			
	Avery Demission	Thvate	(PEID labels)			
	9 ranchac	Privata	(NID labels)			
	oralicites	Filvate	o partner faitcles			
	University of	Public	Education, blockchain code for first			
	Wyoming		shipment			
	Tru-Test (now	Private	Advanced animal performance			
	Datamars)		monitoring (originally New-Zealand,			
			now Datamars, Switzerland)			
	USDA	Public	Certification for Process Verified			
			Program			
Description						
Reason to start the project	Free range cat	tle is a commodity	that is difficult to monetize without			
	giving incontro	overtible proof to the	ne end consumer.			
	Rancher who a	liligently raised a c	cow on the open range often receives a			
	price similar to	that of a cow rais	ed in unknown conditions.			
Start date	2018					
Preconditions	Cows need to	be RFID tagged to	be able to trace			
assumed before starting						
Introduction	Create "ranche	er-centric" supply o	chain utilizing blockchain to recapture			
objectives, preparations	the value now	realized by third-p	party feedlots and processors.			
	Create end-to-	end supply chain s	solution "Rancher to Retail" through			
	BeefChain inve	estment in feedlot	and processing operations offering			
	exclusive, lond	-term relationship	s with buyers across the globe.			
Procedure	Campstool Rar	nge tagged 323 cal	ves with RFID, Persson Ranch kicked			
which steps were taken	off next phase	of the BeefChain t	agging 250 calves followed by Pumpkin			
	Buttes Ranch.	the third founding	member (2018)			
	BeefChain corr	pleted the first blo	ockchain-based shipment of beef from			
	North America	to Asia (February	2019)			
	Received U.S.	Department of Ag	riculture certification (mid 2019)			
	Tagged roughl	v 10 000 head of c	cattle to date (Sept. 2019)			
Results	Producers enro	olled in the program	mme have performed at a minimum of			
or success scenario	10 cents above	a average per pour	d - a considerable amount of money			
when still in progress	when you're ta	e average per pour	a considerable amount of money			
	nieco		innais each weighing 500 pounds a			
	Piece.	plated the first blo	ockchain bacad chinmant of boof from			
	BeerChain Con	to Acia in Fohruar				
	North America		y 2019.			
	Customers in i		alle journey their steek (high guality)			
		a snowing / 500-n	nie journey their steak (nigh quality,			
	DIOCKCHAIN-tra	скец, wyoming-ra	nched beer) had been on to reach their			
	plate, including	y exact ranch locat	ion, putchery information, import date.			
Conclusions	A successful pilot	involving 8 ranch	es in Wyoming, nation's leader in			
	blockchain techn	ology, was reporte	a in the form of a beef shipment using			
	the Ethereum pla	attorm. Information	n about the status of the project after			
	Sept, 2019 has r	ot been found. It o	can be linked to climate change because			
	the cattle is fed r	natural feed (organ	nic). The argument for using Blockchain			

	is much more related to fair payment for the ranches, circumventing the
	middlemen in the value chain. Current status in 2020 unknown.
Follow-up activities	Unknown, the details are scarce.
Organizational	
Potential business benefits from blockchain use	 Circumvent the middlemen (feedlot, food processors) and capture more of the premium pricing. Future versions could include farmer payment.
Potential governance benefits from blockchain use	Decentralized tracing of beef, proving its origin and way of production comes with the benefit of trust in the value chain partners. Consumer has an interest in the value generated in the network.
Special concerns <i>political, environmental, social, technical,</i> <i>economic, legal, etc.</i>	 Concerns have been raised in general on using Proof of Work consensus mechanism due to the electricity necessary for running the Blockchain solution. Animal welfare should be taken into account when tagging, tracing and gathering data.
Technical features	
Used blockchain framework <i>incl. short motivation for this choice</i>	The solution Beefchain.io is the blockchain traceability platform running on the Ethereum protocol, although the grey literature is not conclusive on the final choice of technical supplier. It seems an IT student from the University finally created the platform after having considered other players in the market (TE-Food and IBM Food Trust).
Type of blockchain (public, private, hybrid)	Semi-permissioned blockchain. Access to people permissioned to be in the system, and the rights to this data would be sold with the cow. Some information like date of birth, vaccines, location, and breed may be public, but carcass weight, USDA grading or any other proprietary information could be permissioned, and only accessed by the owner of the cow/beef.
Type of consensus algorithm used	Proof-of-work (POW)
Use of smart contract	N/A
Use of tokens	No (Other beefchain (AUS) does use tokens, see Beefledger
Use of any special hardware or techniques	RFID
e.g. IoT, QR, RFID, LoRa, etc.	
Connection with existing	N/A
databases/systems/ERPs	
Open-source software being used/proposed	N/A
used/proposed Links to related information incl. technical white papers	https://www.forbes.com/sites/michaeldelcastillo/2018/05/17/free-range-beef-bound-by-the-blockchain/#46efee12796a https://www.npr.org/sections/thesalt/2018/08/15/639001393/this-wyoming-company-is-trying-to-put-blockchain-to-use-in-the-agriculture-indus?utm_campaign=storyshare&utm_source=twitter.com&utm_medium=social&t=1588161570655 https://thesheridanpress.com/120531/lawmakers-former-ceo-reachsettlement-on-beefchain/ https://www.coindesk.com/most-influential/2019/caitlin-long https://www.coindesk.com/most-influential/2019/caitlin-long https://medium.com/te-food/te-food-technology-used-to-track-premium-wyoming-beef-on-blockchain-2351ef105cd5 https://repository.upenn.edu/cgi/viewcontent.cgi?article=1073&context=sire https://www.ibm.com/blogs/think/2018/10/how-wyoming-ranchers-arecounting-on-ibm-blockchain-for-traceability/ https://www.northernag.net/first-ever-blockchain-beef-shipment-traced-from-wyoming-to-taiwan/ https://www.thefencepost.com/news/wyomings-beefchain-first-blockchain-company-in-the-world-to-receive-usda-certification/ https://www.youtube.com/watch?v=alyvm_BKeak https://docs.ethhub.io/ethereum-roadmap/ethereum-2.0/eth-2.0-phases/ https://rfid.averydennison.com/en/home/about-us/newsroom/avery-dennison-rfid-blog/blockchain-is-bringing-trust-back-into-the-beef-industry.html

EthicHub

General						
Title of use case	EthicHub					
Website	https://medium	.com/ethichub				
	https://ethichul	b.com/				
Sector and product	Market place in	which companies car	purchase coffee , and crowd lending			
	to small farmers					
Status	Active (Coffee is marketed and internationally crowd lends to small farmers					
	in Maxico)					
Goal	EthicHub is a so	cial enternrise initiat	ive that wants to improve the socio-			
may 1-2 sentences	economic condit	tions of small farmer	s in developing countries facilitating			
max. 1-2 sentences	their financial ir		pair productivity improving the			
	their financial inclusion, increasing their productivity, improving the					
	conditions of sale of their production and creating a digital credit identity					
Climate change adaptation or mitigation	Adaptation					
Kow actors involved	Actor	Bublic / Brivato	Polo (initiator funding toch			
Rey actors involved	ACIO	Public/ Private	other)			
	LendingDev	Private	Start-up initiator operator			
	Coffee	Private				
	Farmers	Tivate				
	Intor	Privata	Einancing, coaling up			
	American	Filvale	r mancing, scaling up			
	Development					
	Bank (IDB)					
	Balik (IDB)					
Description	Financial in d					
Reason to start the project	Financial Inclu	usion in the surface of the	d in an a final state of the st			
	Use blockcha	In to unlock credit an	a improve efficiency and trust in			
			as in Neurophan 2017			
Start date			ce in November 2017			
Preconditions	Small farmer	s have limited access	to bank loans			
assumed before starting	Investors are	looking for a higher	profitability or want to generate social			
			atura eta fare artikara antikara a ³⁴			
	Large compare last last last last last last last last	nies want to close co	intracts for confee purchases			
	Guarantee loa	an repayment to the	investor from the beginning because of			
Tatuaduatian			aradit at a lower cost to increase their			
	Small farmers will have access to credit at a lower cost to increase their production					
objectives, preparations		l obtain higher profits	ar want to concrate assial impact			
	Investors will obtain higher profits or want to generate social impact					
Dreadure	Large comparison		lief annual conee purchases			
which stops were taken	Prontable agricu	a via the traditional k	varking and investment markets			
	. In the first st					
	• In the first st	ill pood to opop a ba				
		nii need to open a ba	The account and a crypto com exchange			
		tago borroworg will	he able to directly dispess of crypte			
	• In a second s	n wallots by paving r	be able to unectly dispose of crypto			
		n wallets by paying a	at any shop accepting visa, without the			
	In the third of	tago decentralized o	vehance points like the ones being			
	developed by	Dether will be instal	led in the farmers' villages and even			
	avoiding the	involvement of Vice	red in the farmers vinages dilu even			
Poculto		a started in Chienes	Máxico with small coffee producers			
	- The prototype	e starteu in Uniapas,	mexico, with small coffee producers.			
or success scenario		and they have not it	ni and gotten their first loans (nearly			
when sum in progress		Thicklub bac man				
	- At unis time,	attorm that has also	eu lo spredu out di operational			
	DIOCKCHain Plan	auonn uiat nas alrea	uy neipeu more unan 120 families			

 ³⁴ https://icobench.com/ico/ethichub
 ³⁵ https://www.disruptordaily.com/blockchain-in-agriculture-use-case-ethichub/

	1
	- Before interest rates on loans was above 100% annually. Now, with
	EthicHub these same farmers can have more resources and rates below
	30% ³⁶
Conclusions	Small farmers will have access to credit at a lower cost while investors have
	were not confronted with default risks
Follow-up activities	The Inter-American Development Bank (IDB) announced that it will
	contribute USD 600 000 to EthicHub to:
	• Scale-up investments by small farmers in Chiapas using blockchain
	technology
	Develop new platform functionalities
	• Commence a pilot in a second country ^{37 38}
Organizational	
Potential business benefits from	Transfer value over the internet in a secure way, transparent, fast and
blockchain use	almost free of cost (for small farmers, investors and trading companies
	without middlemen and banks)
Potential governance benefits from	Democratising credit access to small farmers
blockchain use	
Special concerns	Decentralized audits are carried out by the EthicHub Ambassadors to
political environmental social technical	ensure financial inclusion
economic legal etc	Impact in the small farming communities will be measured by the
	Universided Autónome de Medrid to shed light on the key issues
	A Guarantee Fund is proposed to mitigate the default risk and exchange
	• A Guarance rund is proposed to mitigate the default risk and exchange
Technical features	
lised blockchain framework	Etheroum, dApp as the platform better represents the ideology of EthicHub
incl short motivation for this choice	Etheredin, dapp as the platform better represents the lacology of Etheriab
Type of blockchain (public private	Public
hybrid)	
Type of consensus algorithm used	Proof-of-work
lise of smart contract	All the husiness relationships (between small farmers, investors and trading
	companies) are conducted by smart contracts giving full transparency and
	immutability by automatizing the system at the same time
lise of tokens	Ethix
Use of any special bardware or	N/A
e a lot OR REID LoRa etc	
Connection with existing	N/A
databases /systems / FDDs	
Open-source software being	Ethoroum
used/proposed	
Links to related information	White paper: https://icoshull.com/eng/ico/ethichuh/whitepaper
incl_technical white papers	EthicHub Whitepaper Undate: https://medium.com/ethichub/important-
	announcement-ethichuh-whitenaner-undate-and-2nd-round-token-pre-
	cale-38d00e75813b
	https://www.crupchbase.com/organization/othichub#section-overview
	https://www.chainouropo.org/blockchain_starturg/sthichub/
	https://www.chameurope.org/biockcham-startups/ethichub/
	https://icodealueck.com/ethichub-review/
1	https://icoshull.com/opg/ico/othichuh
	https://icosbull.com/eng/ico/ethichub

 ³⁶ https://startupsreal.com/ethichub-closes-its-1-millions-of-euro-seed-round/
 ³⁷ https://www.contxto.com/en/mexico/inter-american-development-bank-help-small-mexican-farmers-through-blockchain/
 ³⁸ https://startupsreal.com/ethichub-closes-its-1-millions-of-euro-seed-round/

Insurance

General				
Title of use case	Crop insurance Sri Lanka			
Website	https://aon.mediaroom.com			
	https://www.oxfam.org/en			
	https://etherisc.com/			
Sector and product	Paddy rice farming, crop insurance			
Status	Nearly 200 farmers have enrolled in 2019 and envisaged amount of 5 000			
	up to 10 000	in 2020		
Goal	Delivering af	fordable micro crop-i	insurance to smallholder paddy rice	
max. 1-2 sentences	farmers in S	ri Lanka to cope with	extreme weather	
Climate change adaptation or mitigation	Adaptation			
Key actors involved	Actor	Public/Private	Role (initiator, funding, tech, other)	
	Aon	Private	Initiator providing (re-)insurance knowledge	
	Oxfam	Private/NGO	Initiator having deep engagement with	
	Etherisc	Private	Initiator providing knowledge in	
	Ethenise		applying blockchain technology to insurance	
	Sanasa	Private	Providing local expertise, networks and	
Description	insurannce			
Person to start the project	• Dolivorin-	micro cron incurses	2	
Reason to start the project	Delivering Delivering			
	Improving			
Start date	2019	enciency and trust		
Preconditions	Historically	there were major ha	rriers preventing farmers from utilizing	
assumed before starting	insurance in	cludina	mers preventing farmers from dunizing	
	Lack of aff	ordable and reliable	insurance products	
	Lack of un	derstanding about he	ow insurance would help a farmer survive	
	Uncertaint	y when and how a cl	aim would be paid	
Introduction	Goal of the	e first phase is a real	-world, on-the ground blockchain	
objectives, preparations	microinsu	ance solution to help	o farmers	
Procedure	Developin	g a protocol for dece	ntralized collaborative and automated	
which steps were taken	insurance	applications		
	Using wea	ther data index as a	trigger for smart contracts	
	Working w	ith a group of 3 000	farmers to show how the technology can	
	improve the current process insurance products			
Results	Automatic insurance underwriting and settlement of payment to farmers			
or success scenario				
when still in progress				
Conclusions	After the coo	oruinated launch earli	due to extreme weather the system and	
	nav-outs to f	armers in the initial	onerations phase	
Follow-up activities	Refine the	system's efficiency		
	Scale the	number of insured fa	rmers	
Organizational				
Potential business benefits from	Automation	ransforms and simpl	lifies the claims process so	
blockchain use	that a farme	r does not need to su	ubmit a claim, and, at the same time, the	
	insurer does	not need to send a c	laims adjuster into the field. In addition,	
	this process	results in reduced ad	Iministration costs and, subsequently, a	
	higher perce	ntage of premiums b	eing used for claims payment and	
	immediate, f	ully trusted pay-out.		
Potential governance benefits from	Less fraud a	nd more transparence	у	
blockchain use				
Special concerns	In the first s	eason, the group ide	ntified several challenges in the field to be	
political, environmental, social, technical,	improved on going forward:			
economic, legal, etc.	Many farm	 Many farmers in the area lack electronic devices and Internet access. 		
	This mean	s the project may loo	ok to provide offline solutions and/or	

	 devices through local insurance support from Sanasa, to facilitate registration in the group policy The project may need to build a network of additional data sources to round out the automated data provided by weather stations Farmers commonly manage transactions with cash or cheques only. This inhibits the process of automated payouts which, in turn, requires research of additional mobile payment options in Sri Lanka.
Technical features	
Used blockchain framework	Based on Ethereum due to solid protocol for smart contracts and strong
incl. short motivation for this choice	 community. The Generic Insurance Framework (GIF) includes: Core smart contracts (provided by the DIP Foundation and partners) Microservices Application or product specific smart contracts
Type of blockchain (public, private,	Private
hybrid)	
Type of consensus algorithm used	Proof of Stake (PoS)
Use of smart contract	The DIP protocol is a collection of Smart Contract Templates, Rulebooks, Standards, Best Practices which are developed and maintained by the community
Use of tokens	Dai (Etherisc is using a token sale to fund this idea and has already raised enough money for a few developers to start work on this protocol. Cryptocurrencies provide a lot of flexibility to the decentralized insurance model and Etherisc is using a stable coin called Dai that is tied to the US dollar)
Use of any special hardware or	N/A
techniques e.g. IoT, QR, RFID, LoRa, etc.	
Connection with existing	Using weather data as oracle for smart contracts
databases/systems/ERPs	
Open-source software being	Decentralized insurance applications on the Ethereum blockchain
used/proposed	Smart contract that is freely available to copy and use
Links to related information	White paper:
incl. technical white papers	https://tokenmarket.net/blockchain/ethereum/assets/etherisc/ Mechanics: ttps://etherisc.com/files/token_mechanics_1.0_en.pdf https://www.enterprisetimes.co.uk/2019/07/02/aon-oxfam-and-etherisc- launch-blockchain-based-agricultural-insurance/ https://cryptokoers.com/waarde-prijs-koers-euro/DAI/dai/

Landlayby

General				
Title of use case	Land LayBy			
Website	https://hrbe.io/			
Sector and product	Agriculture, registration land titles to enable credit			
Status	After a pilot scheme in Kenya, Land LayBy has scaled			
	up their services to Australia, Ghana, London and New			
	York ³⁹			
Goal	Making landow	nership more trar	sparent and affordable in Sub-Saharan	
max. 1-2 sentences	Africa and othe	er developing nation	ons by recording land ownership by means	
	of blockchain t	echnology		
Climate change adaptation or mitigation	Adaptation			
Key actors involved	Actor	Public/Private	Role (initiator, funding, tech, other)	
	Land LayBy	Private	Start-up, initiator, operator	
	Winjit	Private	Technology	
Description				
Reason to start the project	Verified land land as colla	lownership can he ateral	Ip farmers in obtaining credit by using this	
Start date	2014			
Preconditions	Formally obt	taining landowner	status can be a tiresome, frustrating and	
assumed before starting	even dange		status can be a theoonie, hustrating and	
	Some gover	mment officials or	real estate agencies are known for	
	producing fa	ake title deeds		
	Corruption i	s rampant, which	affects both local businesses and foreign	
	investments	6		
Introduction	The platforn	n will make record	-keeping more efficient, especially in the	
objectives, preparations	real estate s	sector where land	titles are too costly, fraudulent practices	
	and extende	and extended legal litigations		
	• The new digital land registry platform will create immutable records for			
	land ownership which are then digitzsed, secured and stored			
	permanently	y on the blockchai	n	
Procedure	The application	n adheres to local	land commission procedures and details	
which steps were taken	the transaction	n history of the lar	nd:	
	Legally verif application	ied land, with trac	eable histories is recorded on the	
	• Users can th	nen access the plat	tform and add extra information about the	
	land			
	Land LayBy	will verify this info	ormation and announce the land as `LLL	
	certified' (La	and LayBy Listed)		
	Potential bu	yers or renters lar	nd can log-in to interact with the current	
	owner			
Results	Automatic sett	lement of transact	tions via smart contract.	
or success scenario	lotal tokens b	ought: 285 /14 Ha	arambee (IHRBE=USD 0.7).	
Conclusions				
Conclusions	and proven			
Follow-up activities	Upscaling to of	ther countries, and	d properties will be verified by a	
	consortium of	advocates who are	e registered to access the platform	
Organizational				
Potential business benefits from	As stated in th	e white paper the	primary business model comprises the	
blockchain use	business of sel	lling land through	land options (derivatives) in Kenya and	
	Ghana by mea	ins of efficient, dig	ital and immutable land registry records	
Potential governance benefits from	Formally obtai	ning landowner st	atus with less fake title deeds and	
blockchain use	corruption			
Special concerns	The land inform	mation will be visit	ble but the land owners privacy will be	
political, environmental, social, technical,	protected by anonymous identification numbers and only be visible once			
economic, legal, etc.	there is a no return commitment to transact between two parties			

³⁹ https://www.cta.int/en/digitalisation/all/article/land-layby-using-blockchain-to-improve-landownership-sid0de9c7e3a-501a-4455-9c0f-808e8eac7410

Technical features	
Used blockchain framework	Platform Ethereum based shared ledger to keep records of
incl. short motivation for this choice	land transactions
Type of blockchain (public, private,	Private
hybrid)	
Type of consensus algorithm used	
Use of smart contract	The Blockchain Registry is a set of smart contracts created to store land
	records on the Blockchain. These records can never be altered, corrupted,
	forged or erroneously replicated ⁴⁰
Use of tokens	Harambee (HRBE) Tokens. These HRBE Tokens are ERC 20 tokens, backed
	by a HOWEY analysis, and delivered as 'utility tokens' for purposes of
	accessing the ecosystem
Use of any special hardware or	N/A
techniques	
e.g. IoT, QR, RFID, LoRa, etc.	
Connection with existing	Records at the Ministry of Lands registry, transforming and transcending
databases/systems/ERPs	
	Producers will also be registered on the platform, but will have exclusive
	access to the DApp (Decentralized Application) to allow them validate land
	transactions
Open-source software being	N/A
used/proposed	
Links to related information	Whitepaper: https://hrbe.io/images/WHITEPAPER_HRBE06022.PDF
incl. technical white papers	

⁴⁰ https://coinpost.news/how-land-layby-kenya-is-betting-on-blockchain-to-confront-land-fraud/

Nori

General			
Title of use case	Nori		
Website	https://nori.com		
Sector and product	Arable farming		
Status	Active (last transactions July 9 th 2020)		
Goal	Nori is the world's only carbon dioxide removal marketplace. It is a		
max. 1-2 sentences	platform that m	akes it easy to fund o	carbon removal, initially generated
	from agricultura	al projects that can st	ore carbon dioxide in soils.
Climate change adaptation or mitigation	Adaptation/Mitig	gation	
Key actors involved	Actor	Public/Private	Role (initiator, funding, tech, other)
	Nori	Private	Initiator, start-up
	COMEY-Farm	Private	USDA-approved carbon removal
			method
	Granular	Private	Tech, agriculture software
	Harborview	Private	Sustainable agriculture
	Tarms	New weefit	Funding, to get her with The network
	Lecustars	Non-profit	Funding, together with The nature
	Cohort		Conservancy
Description	Conort		
Beacon to start the project	• Sponding on	offecte has gone to p	rejects that avoid emissions
Reason to start the project	spending on	fuctions alone are not	enough — we also need to remove
	billions of ton	nes of greenhouse g	ases from the atmosphere if we're to
	avoid the wor	rst effects of climate	change.
	Blockchain he	elps to problem of do	uble-counting carbon credit.
Start date	2017	<u> </u>	
Preconditions	• Farmers calcu	ulate total potential to	onnes of CO ₂ to sell using OMET-
assumed before starting	Planner (http	://comet-planner.com	n).
	Methodologie	s and systems for est	imating and quantifying carbon
	dioxide remov	val will be public and	subject to continuous improvement.
	Implicit in the approach is transparency, science-based metrics, and		
	peer review.		
Introduction	Creates a new	w way for anyone in t	he world to pay to remove excess
objectives, preparations	carbon dioxid	e from the atmosphe	re.
	A Nori Carbor	n Removal Tonne (NR	1) represents one tonne of CO_2 pulled
	voars	nosphere and stored	
Procedure	Prototype by	the end of 2018	
which steps were taken	Proof-of-conc	ent demonstration tr	ansaction representing 10 000 tonnes
	Building a dat	tabase for quantifying	how much carbon is sequestered via
	certain agricu	Iltural practices	
	Nori's Lightni	ng Sale market place	launched Oct, 2019
Results	Tonnes purch	ased: 11 433	
or success scenario	Last registere	ed certificate is from I	Source Companies LLC for 839 Nori
when still in progress	Carbon Remo	oval Tonnes (NRTs) or	n Aug 25 th , 2020
	• Mid 2020, no	CRTs were available	("Your card will not be charged until
	we have tonn	es available for purch	nase.")
	Certification r	not visible on Blockch	ain solution itself ("view on
O maluation a	Blockchain" d	isabled when viewing	certificate).
Conclusions	thou're optored	ers to pay for NRTS In	This commodifies the removal of
	CO ₂ and remove	as the costly matching	aking process that occurs in
	traditional carbo	on offset markets. Th	ere's, however, a danger in assuming
	Nori will be the	miracle cure for clima	ate change.
Follow-up activities	Improvement	s to the platform. su	ch as adding historical farm field data
• • • • • • • • • • • • • • • • • • • •	with Farm Ma	inagement Software	(FMS) integration (Granular).
	Currently Nor	i is focused on soil se	questration in croplands and will plan
	to add manad	aed grazing projects a	and agroforestry methods.

	Full-line carbon-removal marketplace for investors, corporations and athen large and selling to large the series 2020
Overanizational	other large-scale buyers and sellers to launch in early 2020.
Organizational	Nevi collecte e 10.15% two section for to help loss the meriletalese
	Nori collects a 10-15% transaction fee to help keep the marketplace
Use Detential governance herefits from	Furning.
blockchain use	and used for removing carbon
Special concerns	Ouantifying carbon dioxide removal by supplier projects peeds stringent
political environmental social technical	verification
economic, legal, etc.	Concerns have been raised in general on using Proof of Work consensus
	mechanism due to the electricity necessary for running the Blockchain
	solution.
Technical features	
Used blockchain framework	Ethereum blockchain featuring smart contracts and the Ethereum Virtual
incl. short motivation for this choice	Machine in order to run decentralized applications (dApps). Ethereum
	started with a version of proof of work similar to Bitcoin with the intention
	to transition over to proof of stake, free training, popular open-source
	project with many eyes on the code and a diverse set of applications.
Type of blockchain (public, private,	Public, outside observer can trace the history of who removed the CO ₂ ,
hybrid)	how it was verified to be removed, who purchased the CRCs, and when
	the transaction took place.
Type of consensus algorithm used	Proof of Work
Use of smart contract	Ethereum smart contracts (Solidity programming language)
Use of tokens	NORI token is the cryptocurrency that may be traded in secondary
	cryptocurrency markets.
Use of any special hardware or	N/A
techniques	
techniques e.g. IoT, QR, RFID, LoRa, etc.	
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing	Connections with FMS.
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs	Connections with FMS.
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being	Connections with FMS.
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed	Connections with FMS.
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information	Connections with FMS. N/A https://nori.com/
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://www.crunchbase.com/2018/04/19/oori-fighting.global_warming-with-
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with- blockchain/
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with-blockchain/ bttps://medium.com/nori-carbon-removal/why-nori-needs-its-own-
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with-blockchain/ https://medium.com/nori-carbon-removal/why-nori-needs-its-own-cryptocurrency-token-b2f1eef885c7
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with-blockchain/ https://medium.com/nori-carbon-removal/why-nori-needs-its-own-cryptocurrency-token-b2f1eef885c7 https://medium.com/nori-carbon-removal/why-were-building-a-
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with-blockchain/ https://medium.com/nori-carbon-removal/why-nori-needs-its-own-cryptocurrency-token-b2fleef885c7 https://medium.com/nori-carbon-removal/why-were-building-a-carbon-removal-marketplace-on-ethereum-bba93f4c49fc
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with- blockchain/ https://medium.com/nori-carbon-removal/why-nori-needs-its-own- cryptocurrency-token-b2f1eef885c7 https://medium.com/nori-carbon-removal/why-were-building-a- carbon-removal-marketplace-on-ethereum-bba93f4c49fc https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with-blockchain/ https://medium.com/nori-carbon-removal/why-nori-needs-its-own-cryptocurrency-token-b2fleef885c7 https://medium.com/nori-carbon-removal/why-were-building-a-carbon-removal-marketplace-on-ethereum-bba93f4c49fc https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal https://www.youtube.com/watch?v=XrjhoWY873A&feature=youtu.be
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with-blockchain/ https://medium.com/nori-carbon-removal/why-nori-needs-its-own-cryptocurrency-token-b2f1eef885c7 https://medium.com/nori-carbon-removal/why-were-building-a-carbon-removal-marketplace-on-ethereum-bba93f4c49fc https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal https://www.youtube.com/watch?v=XrjhoWY873A&feature=youtu.be https://www.kqed.org/news/11697942/add-climate-change-to-the-list-of-
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with-blockchain/ https://medium.com/nori-carbon-removal/why-nori-needs-its-own-cryptocurrency-token-b2f1eef885c7 https://medium.com/nori-carbon-removal/why-were-building-a-carbon-removal-marketplace-on-ethereum-bba93f4c49fc https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal https://www.youtube.com/watch?v=XrjhoWY873A&feature=youtu.be https://www.kqed.org/news/11697942/add-climate-change-to-the-list-of-things-blockchain-is-supposed-to-solve
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with- blockchain/ https://medium.com/nori-carbon-removal/why-nori-needs-its-own- cryptocurrency-token-b2f1eef885c7 https://medium.com/nori-carbon-removal/why-were-building-a- carbon-removal-marketplace-on-ethereum-bba93f4c49fc https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal https://www.kqed.org/news/11697942/add-climate-change-to-the-list-of- things-blockchain-is-supposed-to-solve https://www.greenbiz.com/article/can-blockchain-catalyze-carbon-removal
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with-blockchain/ https://medium.com/nori-carbon-removal/why-nori-needs-its-own-cryptocurrency-token-b2f1eef885c7 https://medium.com/nori-carbon-removal/why-were-building-a-carbon-removal-marketplace-on-ethereum-bba93f4c49fc https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal https://www.youtube.com/watch?v=XrjhoWY873A&feature=youtu.be https://www.kqed.org/news/11697942/add-climate-change-to-the-list-of-things-blockchain-is-supposed-to-solve https://www.greenbiz.com/article/can-blockchain-catalyze-carbon-removal https://nori.com/podcasts/carbon-removal-newsroom/nori-lightning-sale-is-
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with-blockchain/ https://medium.com/nori-carbon-removal/why-nori-needs-its-own-cryptocurrency-token-b2f1eef885c7 https://medium.com/nori-carbon-removal/why-were-building-acarbon-removal-marketplace-on-ethereum-bba93f4c49fc https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal https://www.youtube.com/watch?v=XrjhoWY873A&feature=youtu.be https://www.kqed.org/news/11697942/add-climate-change-to-the-list-of-things-blockchain-is-supposed-to-solve https://nori.com/podcasts/carbon-removal-newsroom/nori-lightning-sale-is-now-live
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with-blockchain/ https://medium.com/nori-carbon-removal/why-nori-needs-its-own-cryptocurrency-token-b2f1eef885c7 https://medium.com/nori-carbon-removal/why-were-building-a-carbon-removal-marketplace-on-ethereum-bba93f4c49fc https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal https://www.greenbiz.com/article/can-blockchain-catalyze-carbon-removal https://nori.com/podcasts/carbon-removal-newsroom/nori-lightning-sale-is-now-live https://agfundernews.com/noris-carbon-marketplace-approves-locus-
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with-blockchain/ https://medium.com/nori-carbon-removal/why-nori-needs-its-own-cryptocurrency-token-b2f1eef885c7 https://medium.com/nori-carbon-removal/why-were-building-a-carbon-removal-marketplace-on-ethereum-bba93f4c49fc https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal https://www.greenbiz.com/article/can-blockchain-catalyze-carbon-removal https://www.greenbiz.com/article/can-blockchain-catalyze-carbon-removal https://nori.com/podcasts/carbon-removal-newsroom/nori-lightning-sale-is-now-live https://agfundernews.com/noris-carbon-marketplace-approves-locus-rhizolizer-soil-amendment-for-co2-drawdown-on-croplands.html
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. N/A https://nori.com/ https://www.crunchbase.com/organization/nori#section-overview https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with-blockchain/ https://medium.com/nori-carbon-removal/why-nori-needs-its-own-cryptocurrency-token-b2f1eef885c7 https://medium.com/nori-carbon-removal/why-were-building-a-carbon-removal-marketplace-on-ethereum-bba93f4c49fc https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal https://www.youtube.com/watch?v=XrjhoWY873A&feature=youtu.be https://www.kqed.org/news/11697942/add-climate-change-to-the-list-of-things-blockchain-is-supposed-to-solve https://nori.com/podcasts/carbon-removal-newsroom/nori-lightning-sale-is-now-live https://agfundernews.com/noris-carbon-marketplace-approves-locus-rhizolizer-soil-amendment-for-co2-drawdown-on-croplands.html https://www.businesswire.com/news/home/20191002005263/en/Carbon-
techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	Connections with FMS. N/A https://nori.com/ https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with-blockchain/ https://cleantechnica.com/2018/04/19/nori-fighting-global-warming-with-blockchain/ https://medium.com/nori-carbon-removal/why-nori-needs-its-own-cryptocurrency-token-b2f1eef885c7 https://medium.com/nori-carbon-removal/why-were-building-a-carbon-removal-marketplace-on-ethereum-bba93f4c49fc https://www.greenbiz.com/article/trend-carbon-markets-get-real-removal https://www.youtube.com/watch?v=XrjhoWY873A&feature=youtu.be https://www.kqed.org/news/11697942/add-climate-change-to-the-list-of-things-blockchain-is-supposed-to-solve https://nori.com/podcasts/carbon-removal-newsroom/nori-lightning-sale-is-now-live https://agfundernews.com/noris-carbon-marketplace-approves-locus-rhizolizer-soil-amendment-for-co2-drawdown-on-croplands.html https://www.businesswire.com/news/home/20191002005263/en/Carbon-Removal-Easily-Nori-Launches-Online-Path

Poseidon

General			
Title of use case	Poseidon		
Website	http://www.poseidon.eco		
Sector and product	Forest conservation		
Status	Ongoing		
Goal	With the blockchain platform "reduce", a minimum of 1 pence is		
max. 1-2 sentences	transacted from the point of sale (an ice cream consumer making a		
	nurchase) to the Poseidon backend, used to nurchase Ocean tokens		
	These are then used for a transaction with the smart contract that holds		
	the carbon credit	ts towards forest o	onservation through the Cordillera Azul
	project, effective	ly rebalanced the	climate impact of the product, moving
	towards the goal	of bridaina the en	nissions gap.
Climate change adaptation or mitigation	Mitigation		5
Key actors involved	Actor	Public/Private	Role (initiator, funding, tech, other)
,	Poseidon	Not for profit	Foundation, initiator
	Ben & Jerry's	Private	Ice cream scoop shop. London
	Stellar	Private	Blockchain tech
	Ecosphere+	Private	Providing the Poseidon ecosystem
		Filvate	with carbon credits (funding forest
	(111000 3.A.,)		project)
	6point6	Privato	Tech - reduce platform integration
	BAC	Private	Car production / transport sector
	Liverpool City	Public	Launching support
	Council	rublic	
Description	council		
Beacon to start the project	• Poduco global	omissions by 22.1	million toppos of CO- by 2021
Reason to start the project	Reduce global	of the UN's 17 Su	stainable Development Coals
	Supporting 15 Nosting this p	of the ONS 17 Su	REDD L programme means that the
	Nesting this pi ratirad carbon	credite over inter	reationally transacted ones are not
	double counte	d	nationally transacted ones, are not
Start data	May 2018 (Doru	u. vian Amazon & Ro	n and lorruc)
Breconditions	• Assumes fores	t conservation the	and Jerrys)
assumed before starting	• Assumes fores		bugh the columera Azur project bruges
	The colution n	gap oods to bo connect	ted to the company's (Point of Sale)
	POS system	eeds to be connect	ted to the company's (Font of Sale)
Introduction	Addresses the	social and environ	mental cost of any product or service
objectives preparations	nurchase	Social and criviton	includine cost of any product of schole
	Objective is to	apply technology	to drive behavioural change by
	empowering r	etailers to transfor	m their customers' engagement with
	their carbon fo	otorint	in their customers engagement with
Procedure	 May 2018: pro 	viect live	
which steps were taken	• 2019: Top cor	tributors invited to	o forest conservation project
	Poseidon Mobi	le Ann v3 Release	
Results	Reduce global	emissions by 22.1	million tonnes of CO_2 by 2021
or success scenario	Supports 13 o	f the UN's 17 Sust	ainable Development Goals
when still in progress	• 73% of Ben ar	nd Jerry's consume	ers in London offer to pay more than
	the minimum	of 1 pence.	
	• In 2019, 3 clie	ents had moved on	to the Poseidon platform (Ben &
	lerry's, BAC, N	/ivobarefoot) realiz	zing real-time bi-directional traceability
	to understand	which carbon cred	lit went to which emissions
Conclusions	The solution prov	vides the ability to	transact grams of carbon fast instead
	of carbon transa	ctions in tonnes of	grams (traditional carbon credit
	certificate proces	s). Current status	in 2020 is not well documented.
Follow-up activities	Poseidon aims to	scale up their solu	ution. With 20% of the retail market on
	board, the globa	l carbon emission	
Organizational	, , , , , , , , , , , , , , , , , , , ,		
Potential business benefits from	Track and manage	ae their carbon foo	tprint through an app that connects
blockchain use	consumers and r	etailers, and allow	s them to see the carbon footprint of
	every purchase t	hey make, and the	en offset it by buying carbon credits.

	Accountability, responsibility and transparency for everyone involved.
Potential governance benefits from	Decentralized tracing of carbon emissions forward to the product comes
blockchain use	with the benefit of trust in the value chain partners. Consumer has an
	interest in the value generated in the network.
Special concerns	Adding the cost of the carbon credits required to cover the carbon
political, environmental, social, technical,	footprint of the production of the item to the end consumer's bill
economic, legal, etc.	Stellar Blockchain requires less energy than centralized systems like
	Visa to function, and has a much smaller carbon footprint.
	Rewarding forest protection and providing education to local farmers
Technical features	
Used blockchain framework	Stellar blockchain, forked from Pipple
incl. short motivation for this choice	Licing AI and blockchain. Beseiden can quickly analyse the carbon
	fostering of any product or convice, and then process carbon credits in
	footprint of any product of service, and then process carbon credits in
	Fractions small enough to rebalance the product or service at point of sale.
	Compared to the vast majority of other blockchain platforms, Stellar
	created an architecture that uses far less electricity and offers significant
	environmental advantages.
Type of blockchain (public, private,	Public
hybrid)	Stellar blockchain
Type of consensus algorithm used	Stellar Consensus Protocol (SCP) (Federated Byzantine agreement):
	decentralized control, low latency, flexible trust, and asymptotic security.
Use of smart contract	On-chain and off-chain smart contracts
Use of tokens	OCEAN tokens to purchase FCC (forest carbon credit)
Use of any special hardware or	N/A
Use of any special hardware or techniques	N/A
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc.	N/A
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing	N/A Retailer POS (Point of Sale) system
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf https://medium.com/@jonnyfreesh/poseidon-a-carbon-ecosystem-on-
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf https://medium.com/@jonnyfreesh/poseidon-a-carbon-ecosystem-on-the-blockchain-8ecab5b9c3c5
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf https://medium.com/@jonnyfreesh/poseidon-a-carbon-ecosystem-on-the-blockchain-8ecab5b9c3c5 https://www.youtube.com/watch?v=u4cpQCdhRGM&feature=youtu.be
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf https://medium.com/@jonnyfreesh/poseidon-a-carbon-ecosystem-on-the-blockchain-8ecab5b9c3c5 https://www.youtube.com/watch?v=u4cpQCdhRGM&feature=youtu.be https://ecosphere.plus/2018/04/13/poseidon-stellar-blockchain-reduce-
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf https://medium.com/@jonnyfreesh/poseidon-a-carbon-ecosystem-on-the-blockchain-8ecab5b9c3c5 https://ecosphere.plus/2018/04/13/poseidon-stellar-blockchain-reduce-carbon-footprint/
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf https://medium.com/@jonnyfreesh/poseidon-a-carbon-ecosystem-on-the-blockchain-8ecab5b9c3c5 https://ecosphere.plus/2018/04/13/poseidon-stellar-blockchain-reduce-carbon-footprint/ https://www.enterprisetimes.co.uk/2018/04/13/poseidon-with-stellar-
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf https://medium.com/@jonnyfreesh/poseidon-a-carbon-ecosystem-on-the-blockchain-8ecab5b9c3c5 https://www.youtube.com/watch?v=u4cpQCdhRGM&feature=youtu.be https://ecosphere.plus/2018/04/13/poseidon-stellar-blockchain-reduce-carbon-footprint/ https://www.enterprisetimes.co.uk/2018/04/13/poseidon-with-stellar-blockchain-to-reduce-carbon-footprint/
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf https://medium.com/@jonnyfreesh/poseidon-a-carbon-ecosystem-on-the-blockchain-8ecab5b9c3c5 https://ecosphere.plus/2018/04/13/poseidon-stellar-blockchain-reduce-carbon-footprint/ https://www.enterprisetimes.co.uk/2018/04/13/poseidon-with-stellar-blockchain-to-reduce-carbon-footprint/ https://ecosphere.plus/2018/11/05/redd-unchained-blockchain-and-
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf https://medium.com/@jonnyfreesh/poseidon-a-carbon-ecosystem-on-the-blockchain-8ecab5b9c3c5 https://ecosphere.plus/2018/04/13/poseidon-stellar-blockchain-reduce-carbon-footprint/ https://www.enterprisetimes.co.uk/2018/04/13/poseidon-with-stellar-blockchain-to-reduce-carbon-footprint/ https://ecosphere.plus/2018/11/05/redd-unchained-blockchain-and-climate-change-mitigation-2/
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf https://medium.com/@jonnyfreesh/poseidon-a-carbon-ecosystem-on-the-blockchain-8ecab5b9c3c5 https://ecosphere.plus/2018/04/13/poseidon-stellar-blockchain-reduce-carbon-footprint/ https://www.enterprisetimes.co.uk/2018/04/13/poseidon-with-stellar-blockchain-to-reduce-carbon-footprint/ https://ecosphere.plus/2018/11/05/redd-unchained-blockchain-and-climate-change-mitigation-2/ http://irep.ntu.ac.uk/id/eprint/37378/1/14593
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf https://medium.com/@jonnyfreesh/poseidon-a-carbon-ecosystem-on-the-blockchain-8ecab5b9c3c5 https://ecosphere.plus/2018/04/13/poseidon-stellar-blockchain-reduce-carbon-footprint/ https://www.enterprisetimes.co.uk/2018/04/13/poseidon-with-stellar-blockchain-to-reduce-carbon-footprint/ https://ecosphere.plus/2018/11/05/redd-unchained-blockchain-and-climate-change-mitigation-2/ http://irep.ntu.ac.uk/id/eprint/37378/1/14593_Howson.pdf https://www.stellar.org/developers/guides/concepts/scp.html
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf https://medium.com/@jonnyfreesh/poseidon-a-carbon-ecosystem-on-the-blockchain-8ecab5b9c3c5 https://ecosphere.plus/2018/04/13/poseidon-stellar-blockchain-reduce-carbon-footprint/ https://www.enterprisetimes.co.uk/2018/04/13/poseidon-with-stellar-blockchain-to-reduce-carbon-footprint/ https://ecosphere.plus/2018/11/05/redd-unchained-blockchain-and-climate-change-mitigation-2/ http://irep.ntu.ac.uk/id/eprint/37378/1/14593_Howson.pdf https://www.stellar.org/developers/guides/concepts/scp.html https://www.stellar.org/2018/11/09/can-buving-ben-ierrys-ire-
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf https://medium.com/@jonnyfreesh/poseidon-a-carbon-ecosystem-on-the-blockchain-8ecab5b9c3c5 https://ecosphere.plus/2018/04/13/poseidon-stellar-blockchain-reduce-carbon-footprint/ https://www.enterprisetimes.co.uk/2018/04/13/poseidon-with-stellar-blockchain-to-reduce-carbon-footprint/ https://ecosphere.plus/2018/11/05/redd-unchained-blockchain-and-climate-change-mitigation-2/ http://irep.ntu.ac.uk/id/eprint/37378/1/14593_Howson.pdf https://www.stellar.org/developers/guides/concepts/scp.html https://redd-monitor.org/2018/11/09/can-buying-ben-jerrys-ice-cream-save-the-cordillera-azul-pational-park-in-peru-featuring-
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf https://medium.com/@jonnyfreesh/poseidon-a-carbon-ecosystem-on-the-blockchain-8ecab5b9c3c5 https://ecosphere.plus/2018/04/13/poseidon-stellar-blockchain-reduce-carbon-footprint/ https://www.enterprisetimes.co.uk/2018/04/13/poseidon-with-stellar-blockchain-reduce-carbon-footprint/ https://ecosphere.plus/2018/11/05/redd-unchained-blockchain-and-climate-change-mitigation-2/ http://irep.ntu.ac.uk/id/eprint/37378/1/14593_Howson.pdf https://www.stellar.org/developers/guides/concepts/scp.html https://redd-monitor.org/2018/11/09/can-buying-ben-jerrys-ice-cream-save-the-cordillera-azul-national-park-in-peru-featuring-ecosphere-althelia-the-noseidon-foundation-redu-blockchain-and-park-in-peru-featuring-ecosphere-althelia-the-noseidon-foundation-reduce-hock-hock-hock-hock-hock-hock-hock-hock
Use of any special hardware or techniques e.g. IoT, QR, RFID, LoRa, etc. Connection with existing databases/systems/ERPs Open-source software being used/proposed Links to related information incl. technical white papers	N/A Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules Stellar Core is open-source backend for storing and moving money https://poseidon.eco/assets/documents/Poseidon-Climate-Rescue.pdf https://medium.com/@jonnyfreesh/poseidon-a-carbon-ecosystem-on-the-blockchain-8ecab5b9c3c5 https://ecosphere.plus/2018/04/13/poseidon-stellar-blockchain-reduce-carbon-footprint/ https://www.enterprisetimes.co.uk/2018/04/13/poseidon-with-stellar-blockchain-to-reduce-carbon-footprint/ https://ecosphere.plus/2018/11/05/redd-unchained-blockchain-and-climate-change-mitigation-2/ http://irep.ntu.ac.uk/id/eprint/37378/1/14593_Howson.pdf https://www.stellar.org/developers/guides/concepts/scp.html https://redd-monitor.org/2018/11/09/can-buying-ben-jerrys-ice-cream-save-the-cordillera-azul-national-park-in-peru-featuring-ecosphere-althelia-the-poseidon-foundation-redd-blockchain-and-the-novernment-of-malta/

Treecoin

General				
Title of use case	Treecoin (should not be confused with TreeChain that offers Tree Coin)			
Website	https://tree-coin.io/			
Sector and product	Forestry			
Status	Ongoing (token offering)			
Goal	The main goal of TreeCoin is to make the world greener through encouraging			
max. 1-2 sentences	and facilitating investment into reforestation and timber cultivation.			
Climate change adaptation or mitigation	Mitigation			
Key actors involved	Actor	Public/Private	Role (Initiator, funding, IT provider, user, other)	
	Global Tree Project AG (TreeCoin)	Private	Initiator, manager	
	La Rivera	Private	Partner, user	
	Investors	Private	Funding	
	Ardor platform	Private	IT provider	
		Private	Grower	
	arower	invace		
Description	grower			
Description	l lu av ata in a bl	a dafawaatatian		
Reason to start the project	- Unsustainable	e deforestation		
<u></u>	- Sustainable t	imper production		
Start date	2018			
Preconditions	- Availability of	f fallow land in Para	aguay	
assumed before starting	- Fast-growing	trees		
	- Investment r	needed		
Introduction	 Creating digit 	tal trust by improvi	ing efficiency, transparency and payment	
objectives, preparations	settlement			
	 Piloting block 	chain		
Procedure	- Research on	the ground with loo	cal partner	
which steps were taken	 Developing p 	latform and blockc	hain protocol	
	- Finding laund	- Finding launching user		
	 Partnering with La Rivera retail network 			
	- Hybrid Toker	n Offering (HTO)		
Results	- plant over 10) million trees in Pa	raguay during its initial stage of the	
or success scenario	plantation, covering more than 12 000 hectares of land in the process			
when still in progress				
Conclusions	Blockchain can production thre	be used to facilitat e traded tokens	e reforestation and sustainable timber	
Follow-up activities	Ongoing refores	station, timber prod	duction and natural conservation activities	
Organizational	5 5	· .		
Potential husiness benefits from	- Tradable ass	ot		
blockchain use	- Dual tokens ((security and paym	ent)	
	- Flexibility in l	buving and trading	earnings in tokens	
Potential governance benefits from	Transparency, a	accountability (aud	itability of transactions and trees planted)	
blockchain use	and easier man	agement		
Special concerns	N A	agement		
political environmental social technical	IN.A.			
economic legal etc				
	Ethorous	(doployment with	mart contract Maturation of armstance	
used blockchain framework	Eulereum, easy	aepioyment with s	smant contract. Maturation of Crypto assets	
	Dubli -			
i ype of blockchain (public, private,	Public			
hybrid)				
Type of consensus algorithm used	ERC20 Smart C	Contract		
Use of smart contract	Yes			
Use of tokens	Hybrid coin (TREE/TXC)			
Use of any special hardware or techniques	N/A			
e.g. IoT, QR, RFID, LoRa, etc.				

Connection with existing databases/systems/ERPs	N/A
Open-source software being	N/A
used/proposed	
Links to related information	https://tree-coin.io/wp-content/uploads//2020/07/White_Paper_2020-07-
incl. technical white papers	11_compressed.pdf
	https://coinworldstory.com/treecoin/
	https://blockpublisher.com/worldwide-tree-plantation-initiative-also-hits-
	blockchain/
	https://cointelegraph.com/press-releases/treecoin-launches-compliant-
	token-offering-to-plant-10-million-trees

Appendix 3 Main features of BCT and Checklist Blockchain applicability and steps in blockchain application

Consensus mechanism	Acronym	Used by Blockchain platforms
Delegated Proof of Stake	DPoS	EOS
Istanbul Byzantine fault tolerant Mechanism	IBFT	Ethereum, Geora
Practical Byzantine fault tolerant Mechanism	PBFT	Hyperledger Fabric
Proof of Burn	РоВ	Slimcoin
Proof of Elapsed Time	PoET	Hyperledger Sawtooth
Proof of Importance (PoI)	PoI	NEM
Proof of Stake	PoS	Steem, Gridcoin
Proof of Work	PoW	Bitcoin, Ethereum
Raft Consensus Algorithm	Raft	Quorum

Table 10A list of consensus mechanisms

Table 11 A list of most used blockchain frameworks in blockchain applications

Blockchain framework	Year of establis <u>hment</u>	Ledger type	Code governance	Language	Cryptocurrency	Consensus mecha <u>nism</u>	Pros	Cons
Bitcoin	2009	Public, permissionless	Bitcoin developers	C++ (bitcoin core)	Bitcoins (BTC), not native tokens (such as omni, counterparty and via RGB through smart contracts)	Proof of Work	Permissionless, Proven resilience, high speed, secure and unlimited scalability (proven with Lightning Network)	Energy consumption
Ripple (XRP)	2012	Public, permissioned	Ripple Labs	C++	XRP	Probabilistic voting	High capacity, ability to cancel transactions	Less scalable, no censorship resistance
Ethereum	2013	Public or private; Permissionless	Ethereum developers	C++, Go, Rust, Smart contracts in Solidity	Ether (ETH), not-native tokens	Proof of Work, Proof of Stake ("Casper") in progress	Popularity, dApps	Energy consumption (PoW), fluctuation of ETC, Not proven scalability and security (PoS), No censorship resistance (ETC fork)
Hyperledger Fabric	2015	Private, permissioned	The Linux Foundation	Go, chaincode (smart contracts) in Go, Javascript, or Java, SDKs in Node.js, Java, Go, REST and Python.	None, currency and tokens via chaincode	PBFT	Enterprise-ready	Complex architecture
MultiChain	2015	Permissioned, private	Coin Sciences	C++	None	Roundrobin schedule	Enterprise, open source	Does not support smart contracts
ΙΟΤΑ	2016	Public	IOTA Foundation	Rust, Go	Yes	Tip Selection Algorithm	Scalability	Functions are limited to IoT
Corda	2016	Private, permissioned	The R3 consortium	Kotlin, Java, JVM	None	Specific understanding of consensus (i.e. notary nodes)	Scalability	Customized to financial sector
Quorum	2017	Permissioned, public	Quorum community	GO, Solidity	None	RAFT, BFT	Enhanced transaction and contract privacy	Native token not possible
Hedera Hashgraph	2018	Public, Permissioned	Hedera Governing Council	Java, Solidity	HBAR	Proof of Stake	Low latency (if permission based)	Relatively unknown

			-
Actor	Role in blockchain ecosystem	Description	Sector
3rd Party implementation provider	Provider of IT solutions	Any third party that offers a service that can be added to the Blockchain system implementation. This third-party software entails Apple store, Google Play, or a third-party website, API, or hardware.	Private
Advocacy groups / blockchain community	Research, governance, community building	Many advocacy groups and companies such as Coinbase, Gemini, Circle, Linux Foundation, Ethereum Alliance, and the Digital Currency Initiative at MIT, ConsenSys, Chamber of Digital Commerce, and Bitcoin Foundation are focusing on the research, governance, and developing of this technology to understand the impact of it.	РРР
Blockchain Application provider	Provider of IT solutions	Companies that provide a framework such as Ethereum Alliance, Linux Foundation, Ripple, Tendermint, and Neo.	Private
Blockchain as a Service (SaaS) provider	Provider of IT solutions	Blockchain Software as a Service (SaaS) providers in the cloud are missing, such as Microsoft Azure and IBM that provide blockchains following a single-click approach.	Private
Companies	User, project member, operator	Companies that aim to use a Blockchain solution or provide / use blockchain data.	Private
Consulting / development service provider	Provider of IT solutions	Blockchain consultancy companies, mostly also providing development of a blockchain solution.	Private
Consumer	Possible user	The consumers or citizen impacted by the added value by data transparency provided by the blockchain solution, often pictured at the end of a value chain.	Private
Government, Regulators, and Law enforcement (GRL)	Supervise, regulate	Intragovernmental bodies, national government, indent watchdogs, international and local law enforcement that try to regulate and enforce the standard for blockchain technology. Examples are the European Union, Central Banks, and the International Organization for Standardization (ISO) and so on (standardization organizations also separately listed).	Public
Hardware / Platform provider	Provider of IT solutions	Providers of mining or IoT hardware. Examples are Bitmain, BitFury Group, Wimoto, Vocore and many others.	Private

Table 12 Actors in a blockchain ecosystem
Actor	Role in blockchain ecosystem	Description	Sector
Investors	Investments, funding	Organizations investing in or providing a financial contribution to the blockchain project, but not directly using it.	Private
NGO	User, promotor, project member, operator	NGO such as OneRelief, European Fair-Trade Association, The Fair-Trade Federation (FTF), Fairtrade International or Fairtrade Labelling Organizations International, and others.	Public
Professional farmers	User, project member	Farmers operating farming businesses in different agricultural sectors	Private
Smallholders	User	Smallholders are small-scale farmers, pastoralists, forest keepers, fishers who manage areas varying from less than one hectare to 10 hectares (cf. FAO), typically in developing countries	Private
Standardization organizations	Developing and managing quality and information standards to enable interoperability	Organizations that provide standards such as ISO, NEN, but also Data / IT standards.	Public
Venture capitalists	Investments, funding	Organizations investing in or providing a financial contribution to the Blockchain project, but not directly using it.	Private
Wallet Providers	Provider of IT solutions	Companies that provide the ability to buy, sell and store cryptocurrency online, such as Coinbase and Blockchain.info.	Private

Checklist for applicability

	Aspects	Remark
1	Multiple parties sharing data	Collaboration needed
2	Multiple parties update data	Consensus by design
3	Data requires verification	Cross-check needed
4	Data needs to be timely and accurate	Real-time synchronization
5	Data needs to be persistent over time	Audit trail required
6	Data modification needs to be transparent	Upon agreed rules
7	Data needs to be tamper resistant	Crytoptography, chain of blocks
8	Intermediaries add complexity and costs	Peer-to-peer network

Comparison between blockchain and other data-sharing solutions

	Blockchain		Relational database		Blockchain + rel. database (combi)		Document-based portal
Comparison criteria:	Portal	API	Portal	API connection	Portal	API connection	SharePoint, OneDrive, Google
		connection					Drive, Slack, Dropbox, etc.
System admin	not needed	not	needed	needed	needed	needed	needed
		needed					
Access management	needed	needed	needed	needed	needed	needed	needed
Transaction oriented	yes	yes	yes	yes	yes	yes	yes
Asset oriented	yes	yes	no	no	yes	yes	no
Protection against hacks	very high	very high	high	high	high	high	high
Confidentiality	high	high	high	high	high	high	high
Access roles	yes	yes	yes	yes	yes	yes	yes
Access permissions (CRUD)	CR	CR	CRUD	CRUD	CR	CR	CRUD
Reliability of input data	low	high	low	high	low	high	low
Performance (transactions per	very low	low	high	very high	low	medium	medium
second)							
Scalability	easy	easy	average	easy	average	easy	difficult
Software/server costs	low	low	low	low	low	low	practically free
Development costs	high	low	high	low	high	low	low
Integration costs	very low	high -	very low	high - very high	very low	high - very high	N.A.
		very high					
Maintenance costs	low	low	low	low	low	low	low
Automate decision-making	possible	possible	possible	less possible	possible	possible	less possible
Automate operations	possible	possible	possible	less possible	possible	possible	less possible
Tamper-proof	yes	yes	no	no	yes	yes	no

Steps in developing blockchain application

Typical phases in developing blockchain application include the following:

- Quick scan for applicability
- In-depth analysis of the current situation and desired scenarios
- Application mock-up and architectural design
- Pilot and user acceptance test

Questions per phase Remark					
Quick scan					
Do you share or exchange information with the other actors?					
Do you trust all the actors in your supply chain?					
Are the interest of the supply chain actors aligned?					
Would you be willing to share information with other actors?					
Do you need a trusted third party?					
In-depth Analysis					
Does your asset have a digital identity?					
Would you be willing to create/build a set of digital assets for your					
asset?					
Questions regarding Smart Contract					
Do you want the Blockchain to store contractual relationship?					
Between whom?					
Do you want to automate task?					
What task do you want to automate?					
Between whom?					
Do you want transparency of information?					
Between whom?					
Do you want to create a Crypto-economy?					
Between whom?					
Do you want to use the existing Cryptocurrency or develop your own					
coin?					
Do you want to develop the system by your own, with a community or					
with a third party?					
What type of community?					
Mock-up: User and Technical Requirements					
Who is the administrator of the network?					
Who can add new record to the data?					
Who can validate the new record to the data?					
Who can view the data?					
Do you want to realize an ICO?					
What are the assets?					
What are the transactions to be recorded?					
Does your transaction need to be high frequency(second)?					
Do you want to store a large amount of information (MB) on the					
Blockchain?					
What type of Token supply management would you implement?					
Does a token connect to single or multiple or shared asset?					
Do you want to realize an ICO?					
Do you want to store a large amount of information (MB) on the					
Blockchain?					

Wageningen Economic Research P.O. Box 29703 2502 LS The Hague The Netherlands T +31 (0)70 335 83 30 E communications.ssg@wur.nl www.wur.eu/economic-research

Wageningen Economic Research REPORT 2020-091 The mission of Wageningen University & Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 6,500 employees (5,500 fte) and 12,500 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.





Wageningen University & Research P.O. Box 29703 2502 LS Den Haag The Netherlands T +31 (0)70 335 83 30 E communications.ssg@wur.nl www.wur.eu/economic-research Food and Agriculture Organization of the United Nations FAO-HQ@fao.org Viale delle Terme di Caracalla 00153 Rome, Italy

