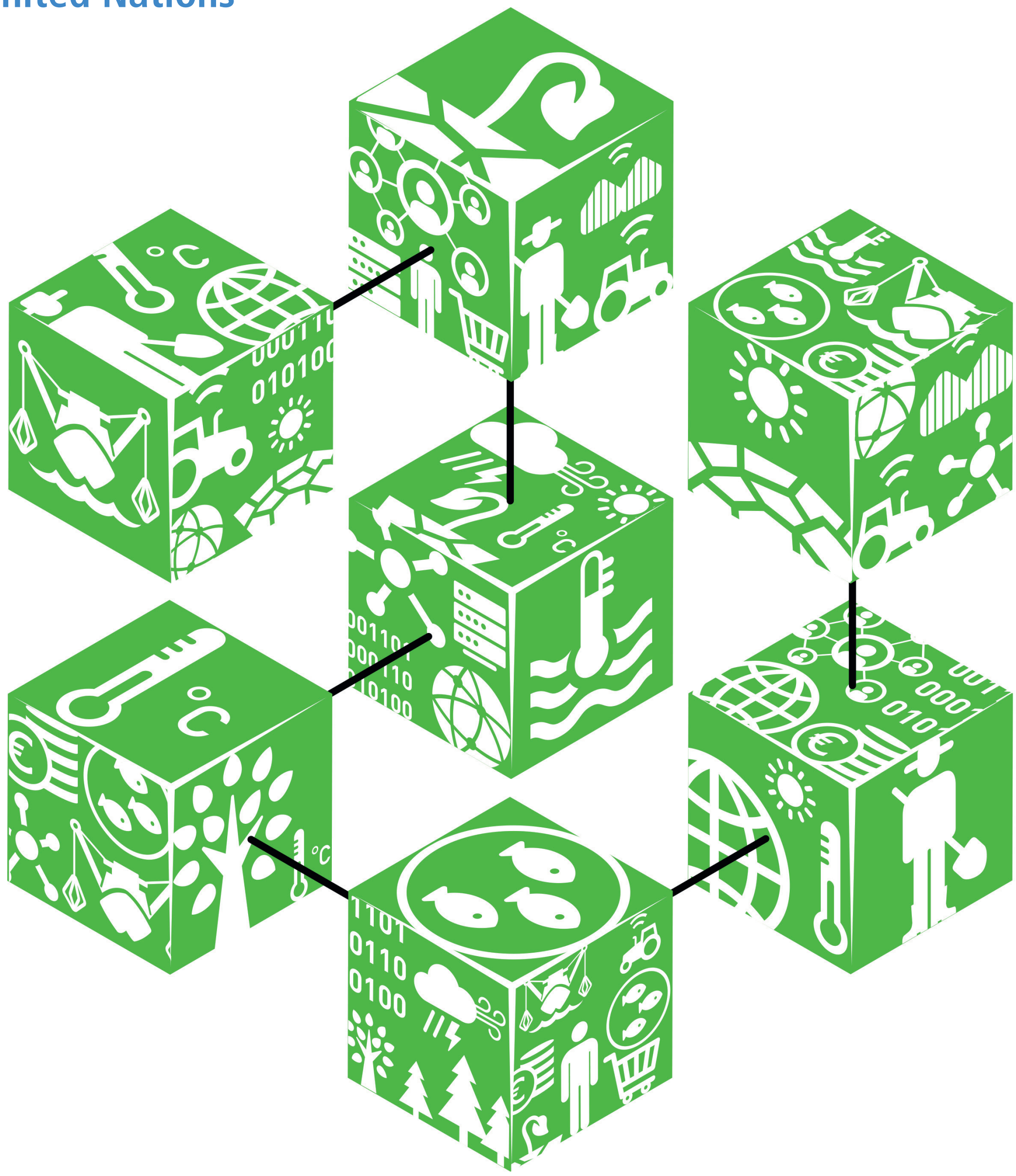
Food and Agriculture
Organization of the
United Nations



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

Background paper

WAGENINGEN
UNIVERSITY & RESEARCH

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

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

Contents

Tables

Figures

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.

Abbreviations and acronyms

API	Application Programming Interface
BCT	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).

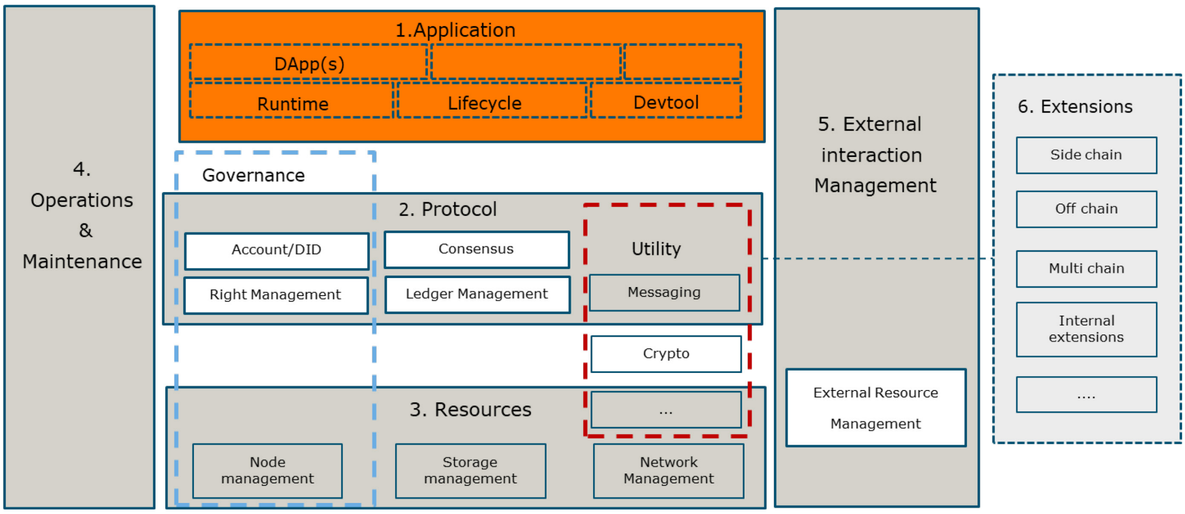


Figure E.1 *Key components of blockchain application (high-level architecture)*
Based on ITU Reference Architecture (ITU-T, 2019)

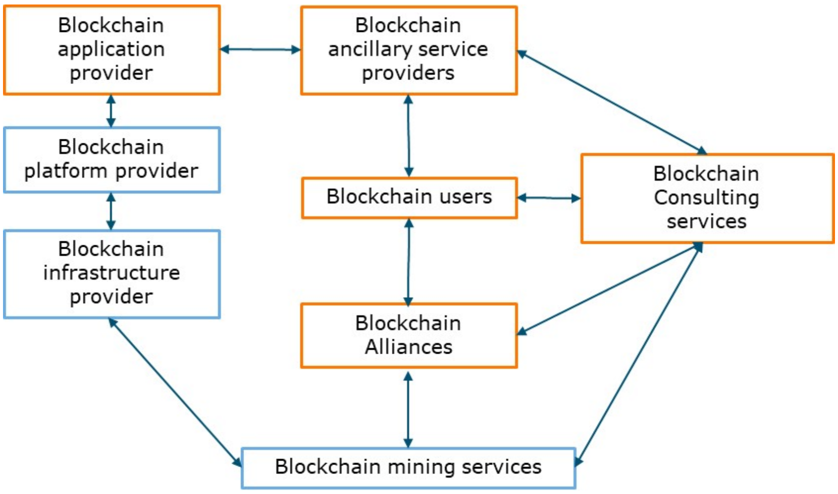


Figure E.2 *Generic blockchain ecosystem, based on Riasanow et al. (2018)*

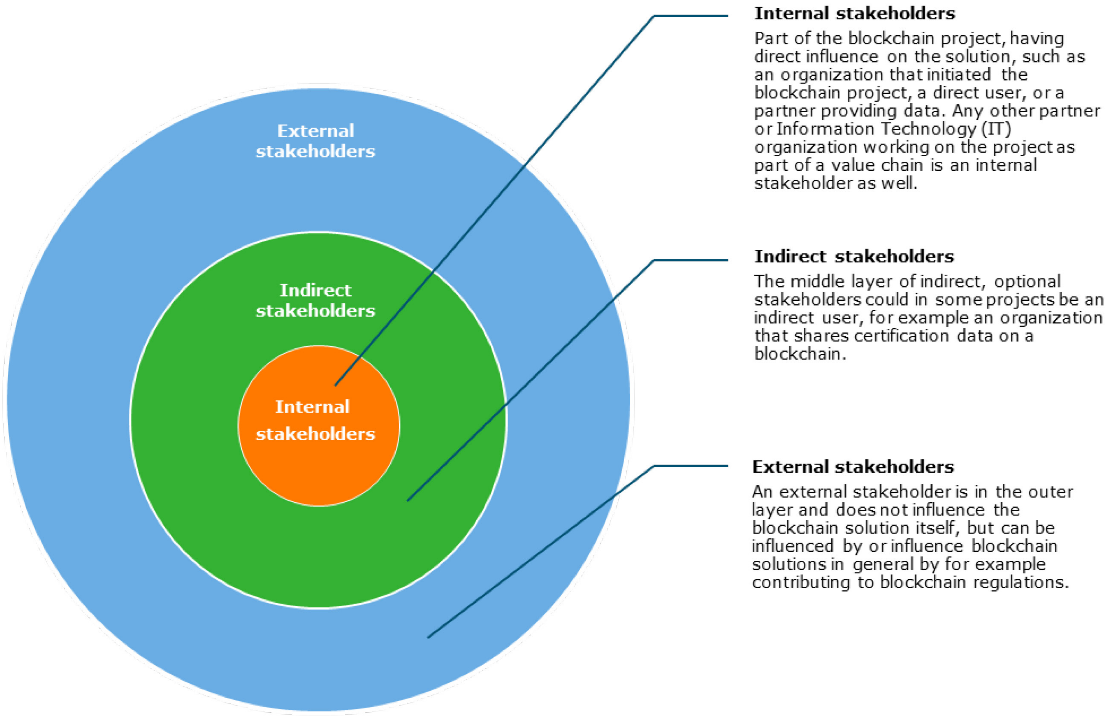


Figure E.3 *Key actors in the blockchain ecosystem*

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. Most use cases are also operated 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' method[1] was applied to locate relevant information. The text-mining software Leximancer[2] 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-Boldů, 2019).

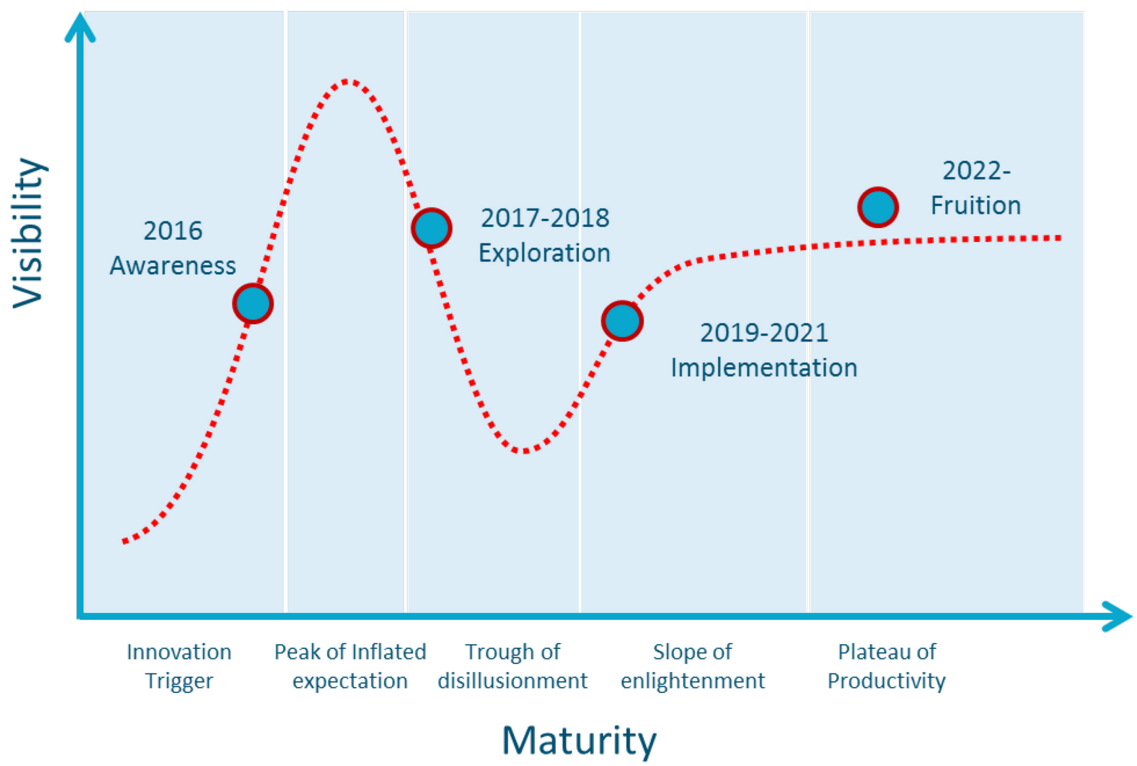


Figure 1 *The (expected) hype cycle of blockchain in agri-food*

[5] Available at: https://www.gartner.com/smarterwithgartner/top-trends-from-gartner-hype-cycle-for-digital-government-technology-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.

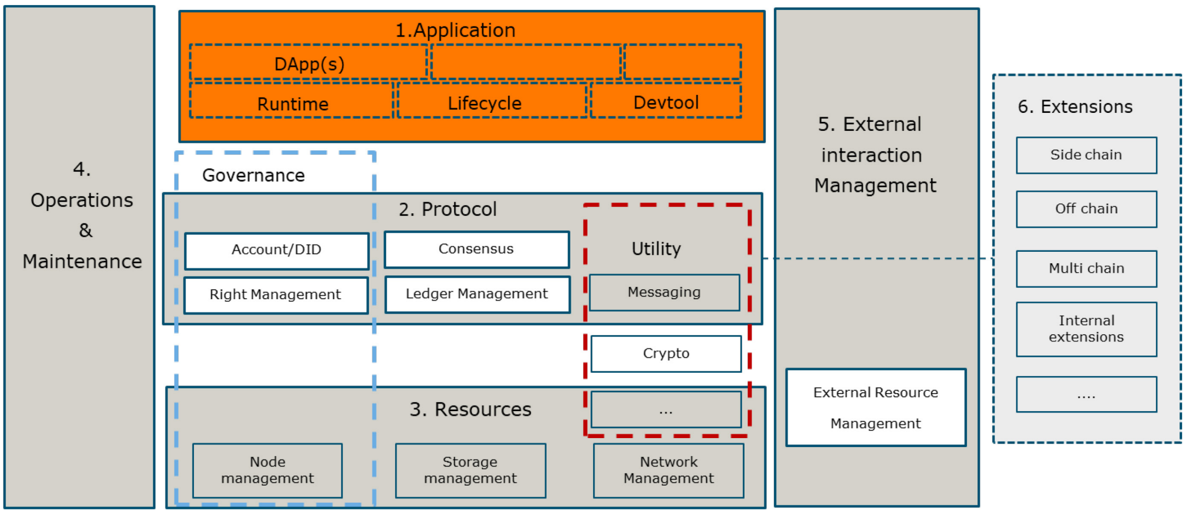


Figure 2 *Key components of blockchain application (high-level architecture)*
Based on ITU Reference Architecture (ITU-T, 2019)

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:

1. 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-hash-function/

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, 2015b; 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 1 *Comparison 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).

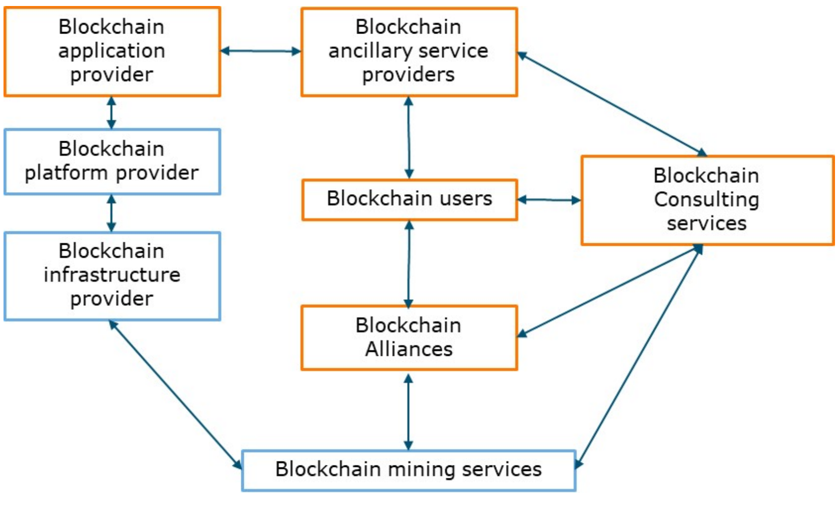


Figure 3 *Generic blockchain ecosystem, based on Riasanow et al. (2018)*

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.

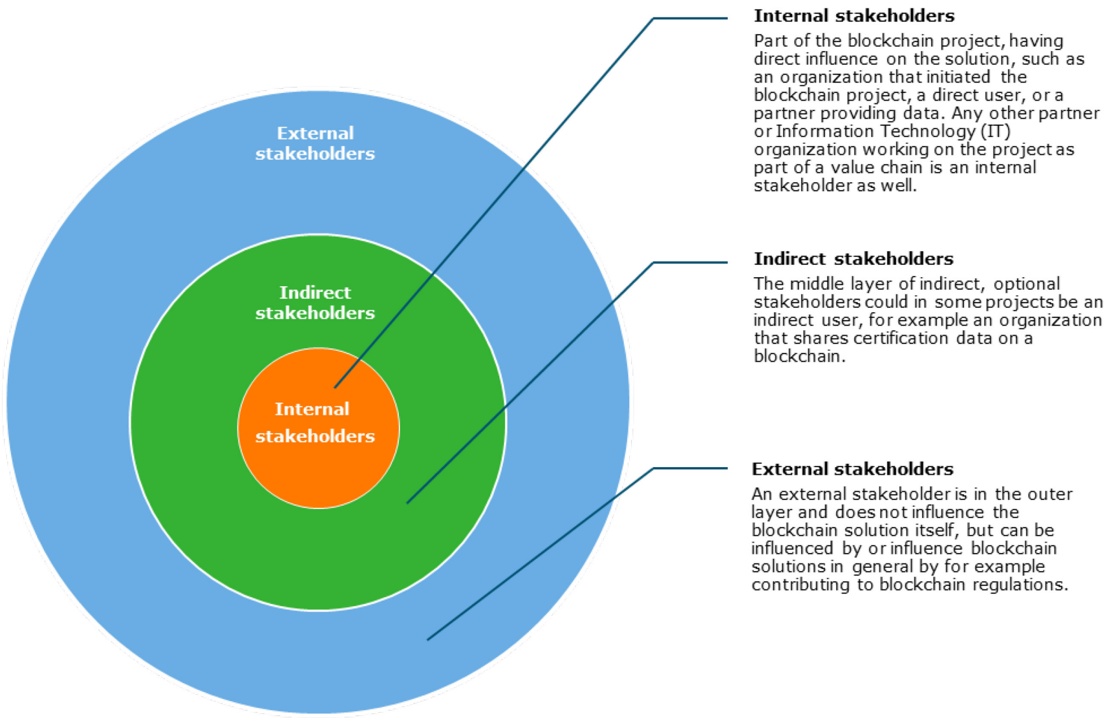


Figure 4 *Key actors in the blockchain ecosystem*

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 CO_2, CH_4, or N_2O. 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 CO_2 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.

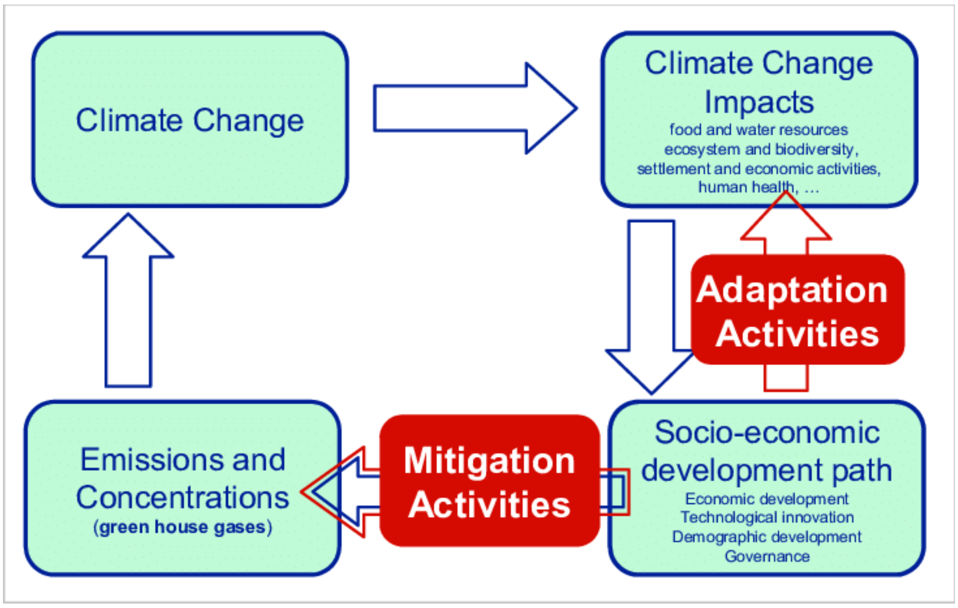


Figure 5 *Climate Change and CCAM activities*
Source: IPCC2001

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.

Table 2 *CCAM Options and topics in Agriculture*

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

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 Foundation[11] 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 CO_2 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) (Sedlmeir *et al.*, 2020). However, blockchain technology is far from homogeneous. Energy consumptions per transaction have a large variation across blockchain architectures (Sedlmeir *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 HashGraph[13] and Zilliqa[14] 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.

Sedlmeir *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/

Sedlmeir *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, Sedlmeir 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.

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

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

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.

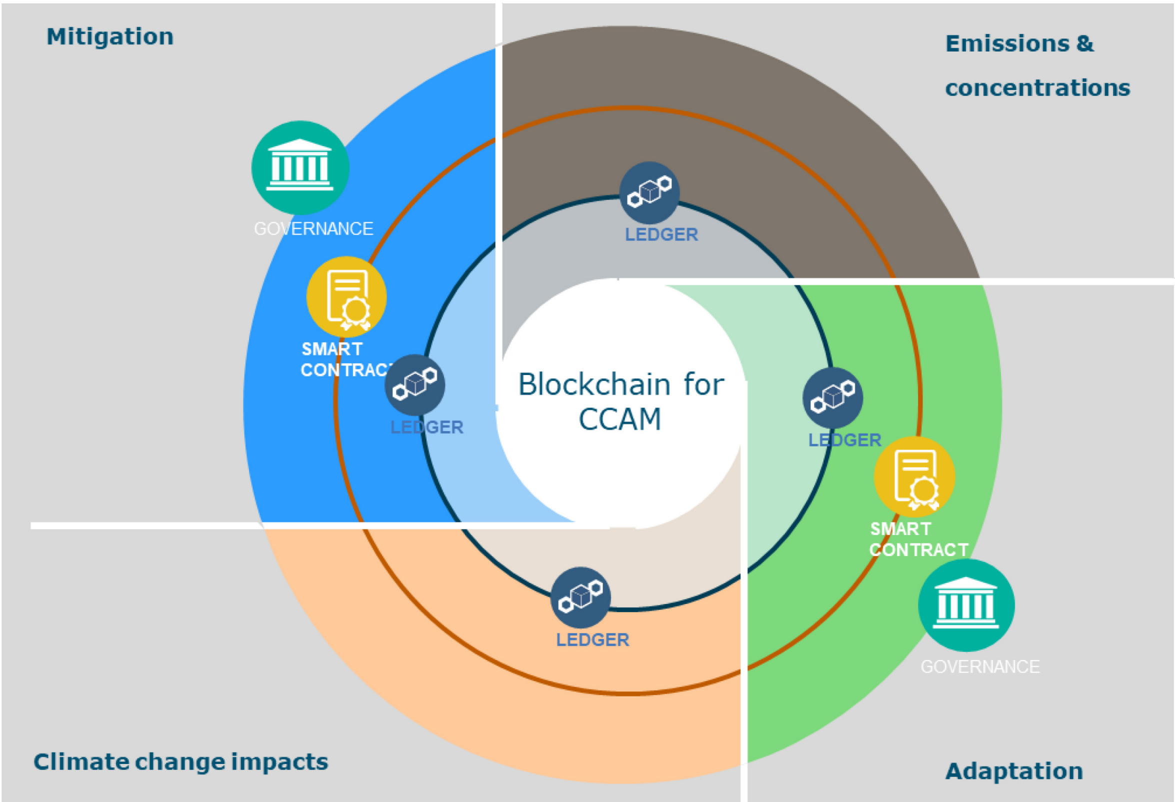


Figure 6 *Blockchain for Climate Change*

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-the-chocolate-industry/

Table 4 *Overview of potential blockchain applications for CCAM in agriculture*

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

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).

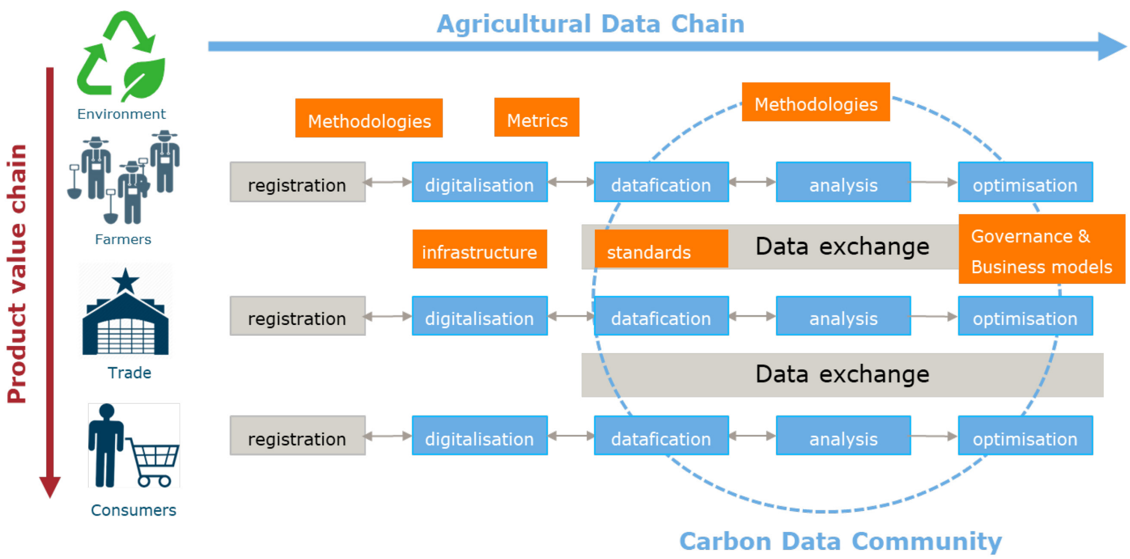


Figure 7 *Challenges of blockchain application in agriculture*

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 Coffee[17] 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 BlocRice[19] aims to help farmers to combat poverty and the NGO Fairfood[20] has demonstrated the value of blockchain in improving smallholders' income in several food value chains (i.e., coconut, coffee, and spices). The blockchain application AgriLedger[21] provides ledger services that are aligned with multiple SDGs including gender equality (SDG5) and climate action (SDG13).

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

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

[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.

Table 6 *Enabling environment for CCAM studied in detail*

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

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).

Table 7 *Overview of blockchain features used in the use cases*

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

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 traders	Permissioned	Non-discriminatory
Agri-wallet	Worldbank, IDH (NGO)	Fintech companies, Farmers, traders, banks	PPP	Dodore (IT services company)	Smallholder farmers and input suppliers	Permissioned, free subscription	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,	PPP	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 indicators[23] 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).

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

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

[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 Standardization[25] 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 to track 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-certification-received-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 platform[33] 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-of-biodiversity-for-food-agriculture/en/.

FAO, 2020a. Carbon footprint of the banana supply chain, http://www.fao.org/world-banana-forum/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-agriculture-sourcebook/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/what-ecosystems-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-Boldύ, 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.
Sedlmeir, 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-use-cases-de494a8f5b60
https://www.itransition.com/blog/blockchain-implementation-guide
https://widgets.weforum.org/blockchain-toolkit/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://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-avoiding-embarrassing-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	Multipurpose, digital trust, less relevant to climate change	Australia	Grain, crops	2015	Adaptation	https://www.agridigital.io/products/blockchain; https://www.disruptordaily.com/blockchain-in-agriculture-use-case-agridigital/
Agriledger		Lan	N	Mainly on efficiency, payment and traceability, less on climate change	UK/Haiti	Food and cash crops	2017	Adaptation	http://www.agriledger.io/
AgUnity		Lan	N	Farmers' identity, payment	Australia, Indonesia, Papua New Guinea, Ethiopia	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	Early phase, similar to Beefchain	Australia	Livestock	2019	Adaptation	https://beefledger.io/
Bext360		Lan	N	focus on traceability and payment	US/Global	All sectors	2016	Adaptation	https://www.bext360.com/
Carbon Cockpit		Lan	N	Early phase, carbon tracking	Switzerland	Non specific	2017	Adaptation	https://www.climateledger.org/en/Use-Cases/Use-case-4.46.html
CarbonX		Lan	N	Carbon trading	Canada	Forestry	2018	Mitigation	https://www.carbonx.ca/
Clean Coin		Lan	N	Farm removed from agriculture, related to Bitcoin and Ethereum	Switzerland	Non specific	2017	Adaptation	http://www.cleancoins.io/files/cleancoin/factsheet.pdf
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, less on agriculture	Switzerland	Non specific	2007/2018	Adaptation/Migitation	https://www.climateledger.org/en/Use-Cases.33.html
Nori		Lan	Y	Carbon sequestration, farmer	US	Arable farming	2017	Adaptation/Migitation	https://nori.com/; https://www.crunchbase.com/organization/nori#section-overview
Redd-Chain Project (RCP)		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/Archive.35.html
Shamba Records		Lan	N	Less focus on climate change	Kenya	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/
SmartCrop (insurance)		Marcel	N	Limited information	China	Non specific	Unclear	Adaptation	https://edepot.wur.nl/472583
Agri-wallet/Coin22/FARMS		Lan	Y	Depending on outreach and information on blockchain	Kenya	Cash crops	2017	Adaptation	https://agri-wallet.com/; https://fairfood.nl/en/blockchain-for-agrifood/case-study-agri-wallet/
Crop insurance Sri Lanka		Marcel	Y	200 farmers in 2019 and 10,000 in 2020. Collaboration by Oxfam, Sanasa, Aon, and Etherisc. Etherisc	Sri Lanka	Arable farming	2019	Adaptation	https://aon.mediaroom.com/2019-07-01-Aon-Oxfam-and-Etherisc-launch-first-blockchain-based-agricultural-insurance-policies-for-smallholder-farmers-in-Sri-Lanka?promo_name=NR-08-2019-09-18-blockchain-agri-ins&promo_position=NR-08
EthicHub (crowd lending)		Marcel	Y	Crowd lending is unlocks private capital	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 involved	Nigeria and Vietnam (expanding to South Africa and East Africa)		2017	Adaptation	https://www.binkabi.io/
Land LayBy		Marcel	Y	Land, finance	Kenya, Ghana	Non specific	2017	Adaptation	https://hrbe.io/
Pure Grow		Marcel	N	Transparency, pilot	Uganda	Crops	2018	Adaptation	
Poseidon		Mireille	Y	Carbon credit trading, AI, reforestation	Global	Agroforesty	2018	Adaptation/Migitation	https://poseidon.eco/ 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 Establishment	CCAM activities	Agrifood sector
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 market	Arable farming
Poseidon	Global	2019	Adaptation/Mitigation	Agroforesty
Treecoin	Switzerland, Paraguay	2018	Mitigation, carbon sequestration	Forestry

AgriDigital

General			
Title of use case	AgriDigital		
Website	https://www.agridigital.io/		
Sector and product	Arable farming, grains		
Status	Several Proof of Concepts (PoCs) and pilots developed, ongoing new projects		
Goal *max. 1-2 sentences*	Creating digital trust in agri-food chains		
Climate change adaptation or mitigation	Adaptation (climate finance)		
Key actors involved	**Actor**	**Public/Private**	**Role** (Initiator, funding, IT provider, user, other)
	AgriDigital	Private, start-up	Initiator, Operator
	CBH Group	Private	Funding, User
	Rabobank	Private	Funding, User
	Fletcher International Export	Private	User
Description			
Reason to start the project	- Piloting blockchain in grains supply chains - Improving efficiency and trust in transactions		
Start date	2015		
Preconditions *assumed before starting*	- Inefficiencies in supply chain - Payment risks for farmers - Start-up AgriDigital working in the grains industry		
Introduction *objectives, preparations*	- Creating digital trust by improving efficiency, transparency and payment settlement - Piloting blockchain		
Procedure *which steps were taken*	- Developing platform and blockchain protocol - Finding launching user - Partnering with CBH group		
Results *or success scenario when still in progress*	Automatic settlement of payment to farmers via smart contract: - Farmers in 3 countries - Two buyers' groups		
Conclusions	Shorter payment terms and transactional transparency for farmers is achievable and proven		

Follow-up activities	Developing new use cases in other countries
Organizational	
Potential business benefits from blockchain use	Efficiency, speed of payment (shorter terms) and payment security
Potential governance benefits from blockchain use	Less fraud, more transparency, removal of counterparty risk for sellers by real-time payment; automating and democratising access to supply chain finance for buyers.
Special concerns *political, environmental, social, technical, economic, legal, etc.*	Privacy of transactional data
Technical features	
Used blockchain framework *incl. short motivation for this choice*	Ethereum based Smart Contract and tokens
Type of blockchain (public, private, hybrid)	Private
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 techniques *e.g. IoT, QR, RFID, LoRa, etc.*	IoT, sensor
Connection with existing databases/systems/ERPs	N/A
Open-source software being used/proposed	Proprietary
Links to related information *incl. technical white papers*	https://www.agridigital.io/reports/blockchain-pilot-report 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 *max. 1-2 sentences*	Improving smallholder farmers' access to finance and high-quality inputs		
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 Foundation	Private	Funding/Donor
	IDH Farmfit fund	Public	Funding/Donor
	FMO	Private	Funding/Donor
	World Bank	Public	Funding/Award/Grant
Description			
Reason to start the project	Smallholder farmers in Kenya often lack access to financial services and inputs due to irregular cash flows		
Start date	2017		
Preconditions *assumed before starting*	- Farmers have access to mobile networks and mobile digital wallet developed with M-Pesa - Loan providers and merchants (input suppliers) accept tokens for purchases and payments and saving - Tokens are earmarked for inputs (seed and fertilizer)		
Introduction *objectives, preparations*	- Agri-Wallet contributes to efficient and reliable agri-finance for farmers with irregular cash flows - Farmers are provided with a free business account that can be used to purchase, sell and save - Payments can be in M-Pesa or tokens - Rabobank provides short-term loans though Agri-Wallet with limited paper work		
Procedure *which steps were taken*	- Developing mobile payment system - Onboarding of farmers, suppliers and other merchants - Publicity through awards and other prizes		
Results *or success scenario when still in progress*	- Value proposition well received in the market, reaching >25 000 farmers in Kenya, partnered with more than 50 buyers and 100 input suppliers - Won multiple awards		
Conclusions			
Follow-up activities	- Scaling up - Developing new use cases in other countries - Partnership with IDH Farmfit Fund and FMO		
Organizational			
Potential business benefits from blockchain use	- Improved access to finance for farmers with less transaction costs and paper work - Improved productivity due to better access to high quality inputs (seed, fertilizer etc.)		
Potential governance benefits from blockchain use	- More transparency - less (default) risk - Inclusiveness (low income, women, youth)		
Special concerns *political, environmental, social, technical, economic, legal, etc.*	Helping the vulnerable people (low income, women, youth) in developing countries		

Technical features	
Used blockchain framework *incl. short motivation for this choice*	Ethereum, enabling smart contracts and the use of tokens
Type of blockchain (public, private, hybrid)	Public/private
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 techniques *e.g. IoT, QR, RFID, LoRa, etc.*	Not yet
Connection with existing databases/systems/ERPs	Connected to mobile payment system M-Pesa
Open-source software being used/proposed	Proprietary
Links to related information *incl. technical white papers*	https://www.cta.int/en/digitalisation/all/article/agri-wallet-a-wallet-for-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://beefchain.com		
Sector and product	Agriculture, livestock		
Status	Unknown		
Goal *max. 1-2 sentences*	BeefChain's RFID tags and other IoT devices upload unique cow/calf information to the blockchain to establish immutable, auditable provenance to better capture the free 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 Certified Beef)
	Avery Dennison	Private	Packaging materials solution company (RFID labels)
	8 ranches	Private	8 partner ranches https://beefchain.com/ranches
	University of Wyoming	Public	Education, blockchain code for first shipment
	Tru-Test (now Datamars)	Private	Advanced animal performance monitoring (originally New-Zealand, now Datamars, Switzerland)
	USDA	Public	Certification for Process Verified Program
Description			
Reason to start the project	• Free range cattle is a commodity that is difficult to monetize without giving incontrovertible proof to the end consumer. • Rancher who diligently raised a cow on the open range often receives a price similar to that of a cow raised in unknown conditions.		
Start date	2018		
Preconditions *assumed before starting*	• Cows need to be RFID tagged to be able to trace		
Introduction *objectives, preparations*	• Create "rancher-centric" supply chain utilizing blockchain to recapture the value now realized by third-party feedlots and processors. • Create end-to-end supply chain solution "Rancher to Retail" through BeefChain investment in feedlot and processing operations offering exclusive, long-term relationships with buyers across the globe.		
Procedure *which steps were taken*	• Campstool Range tagged 323 calves with RFID, Persson Ranch kicked off next phase of the BeefChain tagging 250 calves followed by Pumpkin Buttes Ranch, the third founding member (2018) • BeefChain completed the first blockchain-based shipment of beef from North America to Asia (February 2019) • Received U.S. Department of Agriculture certification (mid 2019) • Tagged roughly 10 000 head of cattle to date (Sept, 2019)		
Results *or success scenario when still in progress*	• Producers enrolled in the programme have performed at a minimum of 10 cents above average per pound — a considerable amount of money when you're talking about 250 animals each weighing 500 pounds a piece. • BeefChain completed the first blockchain-based shipment of beef from North America to Asia in February 2019. • Customers in restaurant scan a QR code connected to the unique RFID digital identifier showing 7 500-mile journey their steak (high quality, blockchain-tracked, Wyoming-ranched beef) had been on to reach their plate, including exact ranch location, butchery information, import date.		
Conclusions	A successful pilot involving 8 ranches in Wyoming, nation's leader in blockchain technology, was reported in the form of a beef shipment using the Ethereum platform. Information about the status of the project after Sept, 2019 has not been found. It can be linked to climate change because the cattle is fed natural feed (organic). 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 *political, environmental, social, technical, 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. • Animal welfare should be taken into account when tagging, tracing and gathering data.
Technical features	
Used blockchain framework *incl. short motivation for this choice*	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 *e.g. IoT, QR, RFID, LoRa, etc.*	RFID
Connection with existing databases/systems/ERPs	N/A
Open-source software being used/proposed	N/A
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-reach-settlement-on-beefchain/ 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-are-counting-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://ethichub.com/		
Sector and product	Market place in which companies can purchase **coffee**, and crowd lending to small farmers		
Status	Active (Coffee is marketed and internationally crowd lends to small farmers in Mexico)		
Goal *max. 1-2 sentences*	EthicHub is a social enterprise initiative that wants to improve the socio-economic conditions of small farmers in developing countries, facilitating their financial inclusion, increasing their productivity, improving the conditions of sale of their production and creating a digital credit identity that can be used in the financial system		
Climate change adaptation or mitigation	Adaptation		
Key actors involved	**Actor**	**Public/Private**	**Role (initiator, funding, tech, other)**
	LendingDev	Private	Start-up, initiator, operator
	Coffee Farmers	Private	User
	Inter-American Development Bank (IDB)	Private	Financing, scaling up
Description			
Reason to start the project	• Financial inclusion • Use blockchain to unlock credit and improve efficiency and trust in transactions		
Start date	The EthicHub official launch took place in November 2017		
Preconditions *assumed before starting*	• Small farmers have limited access to bank loans • Investors are looking for a higher profitability or want to generate social impact • Large companies want to close contracts for coffee purchases[34] • Guarantee loan repayment to the investor from the beginning because of coffee contracts		
Introduction *objectives, preparations*	• Small farmers will have access to credit at a lower cost to increase their production • Investors will obtain higher profits or want to generate social impact • Large companies are guaranteed their annual coffee purchases		
Procedure *which steps were taken*	Profitable agricultural projects are selected in person by a Local Node that aren't accessible via the traditional banking and investment markets • In the first stage of the system, the representative of the farmer community will need to open a bank account and a crypto coin exchange account • In a second stage, borrowers will be able to directly dispose of crypto from their own wallets by paying at any shop accepting Visa, without the necessity of a bank account. • In the third stage, decentralized exchange points like the ones being developed by Dether will be installed in the farmers' villages and even avoiding the involvement of Visa credit cards		
Results *or success scenario when still in progress*	- The prototype started in Chiapas, México, with small coffee producers. Over 60 families joined the platform and gotten their first loans (nearly USD 60 000) and they have paid back on time[35] - At this time, EthicHub has managed to spread out an operational blockchain platform that has already helped more than 120 families		

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

	- 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 blockchain use	Transfer value over the internet in a secure way, transparent, fast and almost free of cost (for small farmers, investors and trading companies without middlemen and banks)
Potential governance benefits from blockchain use	Democratising credit access to small farmers
Special concerns *political, environmental, social, technical, economic, legal, etc.*	• Decentralized audits are carried out by the EthicHub Ambassadors to ensure financial inclusion • Impact in the small farming communities will be measured by the Universidad Autónoma de Madrid to shed light on the key issues • A Guarantee Fund is proposed to mitigate the default risk and exchange rate risk
Technical features	
Used blockchain framework *incl. short motivation for this choice*	Ethereum, dApp as the platform better represents the ideology of EthicHub
Type of blockchain (public, private, hybrid)	Public
Type of consensus algorithm used	Proof-of-work
Use of smart contract	All the business 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
Use of tokens	Ethix
Use of any special hardware or techniques *e.g. IoT, QR, RFID, LoRa, etc.*	N/A
Connection with existing databases/systems/ERPs	N/A
Open-source software being used/proposed	Ethereum
Links to related information *incl. technical white papers*	White paper: https://icosbull.com/eng/ico/ethichub/whitepaper EthicHub Whitepaper Update: https://medium.com/ethichub/important-announcement-ethichub-whitepaper-update-and-2nd-round-token-pre-sale-38d00e75813b https://www.crunchbase.com/organization/ethichub#section-overview https://www.chaineurope.org/blockchain-startups/ethichub/ https://icodealdeck.com/ethichub-review/ https://icosbull.com/eng/ico/ethichub https://releaseyourdigitaltalent.com/ethichub-review-agricultural-platform/

[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 *max. 1-2 sentences*	Delivering affordable micro crop-insurance to smallholder paddy rice farmers in Sri 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 the local farmer community
	Etherisc	Private	Initiator providing knowledge in applying blockchain technology to insurance
	Sanasa insurannce	Private	Providing local expertise, networks and operational execution
Description			
Reason to start the project	• Delivering micro crop-insurance. • Piloting blockchain to scale insurance • Improving efficiency and trust in transactions		
Start date	2019		
Preconditions *assumed before starting*	Historically, there were major barriers preventing farmers from utilizing insurance, including • Lack of affordable and reliable insurance products • Lack of understanding about how insurance would help a farmer survive • Uncertainty when and how a claim would be paid		
Introduction *objectives, preparations*	• Goal of the first phase is a real-world, on-the ground blockchain microinsurance solution to help farmers		
Procedure *which steps were taken*	• Developing a protocol for decentralized collaborative and automated insurance applications • Using weather data index as a trigger for smart contracts • Working with a group of 3 000 farmers to show how the technology can improve the current process insurance products		
Results *or success scenario when still in progress*	Automatic insurance underwriting and settlement of payment to farmers		
Conclusions	After the coordinated launch earlier in 2019 with 200 farmers enrolled who were at risk of losing their crops due to extreme weather the system made pay-outs to farmers in the initial operations phase		
Follow-up activities	• Refine the system's efficiency • Scale the number of insured farmers		
Organizational			
Potential business benefits from blockchain use	Automation transforms and simplifies the claims process so that a farmer does not need to submit a claim, and, at the same time, the insurer does not need to send a claims adjuster into the field. In addition, this process results in reduced administration costs and, subsequently, a higher percentage of premiums being used for claims payment and immediate, fully trusted pay-out.		
Potential governance benefits from blockchain use	Less fraud and more transparency		
Special concerns *political, environmental, social, technical, economic, legal, etc.*	In the first season, the group identified several challenges in the field to be improved on going forward: • Many farmers in the area lack electronic devices and Internet access. This means the project may look 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 *incl. short motivation for this choice*	Based on Ethereum due to solid protocol for smart contracts and strong 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, hybrid)	Private
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 techniques *e.g. IoT, QR, RFID, LoRa, etc.*	N/A
Connection with existing databases/systems/ERPs	Using weather data as oracle for smart contracts
Open-source software being used/proposed	Decentralized insurance applications on the Ethereum blockchain Smart contract that is freely available to copy and use
Links to related information *incl. technical white papers*	White paper: 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 *max. 1-2 sentences*	Making landownership more transparent and affordable in Sub-Saharan Africa and other developing nations by recording land ownership by means of blockchain technology		
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 landownership can help farmers in obtaining credit by using this land as collateral		
Start date	2014		
Preconditions *assumed before starting*	• Formally obtaining landowner status can be a tiresome, frustrating and even dangerous process • Some government officials or real estate agencies are known for producing fake title deeds • Corruption is rampant, which affects both local businesses and foreign investments		
Introduction *objectives, preparations*	• The platform will make record-keeping more efficient, especially in the real estate sector where land titles are too costly, fraudulent practices 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 on the blockchain		
Procedure *which steps were taken*	The application adheres to local land commission procedures and details the transaction history of the land: • Legally verified land, with traceable histories is recorded on the application • Users can then access the platform and add extra information about the land • Land LayBy will verify this information and announce the land as 'LLL certified' (Land LayBy Listed) • Potential buyers or renters land can log-in to interact with the current owner		
Results *or success scenario when still in progress*	Automatic settlement of transactions via smart contract. Total tokens bought: 285 714 Harambee (1HRBE=USD 0.7).		
Conclusions	Land registry transparency for farmers and other investors is achievable and proven		
Follow-up activities	Upscaling to other countries, and properties will be verified by a consortium of advocates who are registered to access the platform		
Organizational			
Potential business benefits from blockchain use	As stated in the white paper the primary business model comprises the business of selling land through land options (derivatives) in Kenya and Ghana by means of efficient, digital and immutable land registry records		
Potential governance benefits from blockchain use	Formally obtaining landowner status with less fake title deeds and corruption		
Special concerns *political, environmental, social, technical, economic, legal, etc.*	The land information will be visible but the land owners privacy will be protected by anonymous identification numbers and only be visible once 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 *incl. short motivation for this choice*	Platform Ethereum based shared ledger to keep records of land transactions
Type of blockchain (public, private, hybrid)	Private
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 techniques *e.g. IoT, QR, RFID, LoRa, etc.*	N/A
Connection with existing databases/systems/ERPs	Records at the Ministry of Lands registry, transforming and transcending 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 used/proposed	N/A
Links to related information *incl. technical white papers*	Whitepaper: https://hrbe.io/images/WHITEPAPER_HRBE06022.PDF

[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 9th 2020)		
Goal *max. 1-2 sentences*	Nori is the world's only carbon dioxide removal marketplace. It is a platform that makes it easy to fund carbon removal, initially generated from agricultural projects that can store carbon dioxide in soils.		
Climate change adaptation or mitigation	Adaptation/Mitigation		
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 Farms	Private	Sustainable agriculture
	Techstars Sustainability Cohort	Non-profit	Funding, together with The nature conservancy
Description			
Reason to start the project	• Spending on offsets has gone to projects that avoid emissions, emissions reductions alone are not enough — we also need to remove billions of tonnes of greenhouse gases from the atmosphere if we're to avoid the worst effects of climate change. • Blockchain helps to problem of double-counting carbon credit.		
Start date	2017		
Preconditions *assumed before starting*	• Farmers calculate total potential tonnes of CO_2 to sell using OMET-Planner (http://comet-planner.com). • Methodologies and systems for estimating and quantifying carbon dioxide removal will be public and subject to continuous improvement. Implicit in the approach is transparency, science-based metrics, and peer review.		
Introduction *objectives, preparations*	• Creates a new way for anyone in the world to pay to remove excess carbon dioxide from the atmosphere. • A Nori Carbon Removal Tonne (NRT) represents one tonne of CO_2 pulled out of the atmosphere and stored in the soil for a minimum of ten years.		
Procedure *which steps were taken*	• Prototype by the end of 2018 • Proof-of-concept demonstration transaction representing 10 000 tonnes • Building a database for quantifying how much carbon is sequestered via certain agricultural practices • Nori's Lightning Sale market place launched Oct, 2019		
Results *or success scenario when still in progress*	• Tonnes purchased: 11 433 • Last registered certificate is from E Source Companies LLC for 839 Nori Carbon Removal Tonnes (NRTs) on Aug 25th, 2020 • Mid 2020, no CRTs were available ("Your card will not be charged until we have tonnes available for purchase.") • Certification not visible on Blockchain solution itself ("view on Blockchain" disabled when viewing certificate).		
Conclusions	Nori allows buyers to pay for NRTs in a first-in-first-out (FIFO) order as they're entered into the marketplace. This commoditizes the removal of CO_2 and removes the costly matchmaking process that occurs in traditional carbon offset markets. There's, however, a danger in assuming Nori will be the miracle cure for climate change.		
Follow-up activities	• Improvements to the platform, such as adding historical farm field data with Farm Management Software (FMS) integration (Granular). • Currently Nori is focused on soil sequestration in croplands and will plan to add managed grazing projects and agroforestry methods.		

	• Full-line carbon-removal marketplace for investors, corporations and other large-scale buyers and sellers to launch in early 2020.
Organizational	
Potential business benefits from blockchain use	• Nori collects a 10-15% transaction fee to help keep the marketplace running.
Potential governance benefits from blockchain use	Everyone in this ecosystem benefits when the NORI token is widely traded and used for removing carbon.
Special concerns *political, environmental, social, technical, economic, legal, etc.*	• Quantifying carbon dioxide removal by supplier projects needs stringent verification. • 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 *incl. short motivation for this choice*	Ethereum blockchain featuring smart contracts and the Ethereum Virtual 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, hybrid)	Public, outside observer can trace the history of who removed the CO_2, 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 techniques *e.g. IoT, QR, RFID, LoRa, etc.*	N/A
Connection with existing databases/systems/ERPs	Connections with FMS.
Open-source software being used/proposed	N/A
Links to related information incl. technical white papers	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-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 https://docs.ethhub.io/ethereum-roadmap/ethereum-2.0/eth-2.0-phases/

Poseidon

<table>
<tr><th colspan="4">General</th></tr>
<tr><td>Title of use case</td><td colspan="3">Poseidon</td></tr>
<tr><td>Website</td><td colspan="3">http://www.poseidon.eco</td></tr>
<tr><td>Sector and product</td><td colspan="3">Forest conservation</td></tr>
<tr><td>Status</td><td colspan="3">Ongoing</td></tr>
<tr><td>Goal
max. 1-2 sentences</td><td colspan="3">With the blockchain platform “reduce”, a minimum of 1 pence is transacted from the point of sale (an ice cream consumer making a purchase) to the Poseidon backend, used to purchase Ocean tokens. These are then used for a transaction with the smart contract that holds the carbon credits towards forest conservation through the Cordillera Azul project, effectively rebalanced the climate impact of the product, moving towards the goal of bridging the emissions gap.</td></tr>
<tr><td>Climate change adaptation or mitigation</td><td colspan="3">Mitigation</td></tr>
<tr><td rowspan="8">Key actors involved</td><td>Actor</td><td>Public/Private</td><td>Role (initiator, funding, tech, other)</td></tr>
<tr><td>Poseidon</td><td>Not for profit</td><td>Foundation, initiator</td></tr>
<tr><td>Ben & Jerry’s</td><td>Private</td><td>Ice cream scoop shop, London</td></tr>
<tr><td>Stellar</td><td>Private</td><td>Blockchain tech</td></tr>
<tr><td>Ecosphere+ (Mirova S.A.,)</td><td>Private</td><td>Providing the Poseidon ecosystem with carbon credits (funding forest project)</td></tr>
<tr><td>6point6</td><td>Private</td><td>Tech - reduce platform integration</td></tr>
<tr><td>BAC</td><td>Private</td><td>Car production / transport sector</td></tr>
<tr><td>Liverpool City Council</td><td>Public</td><td>Launching support</td></tr>
<tr><th colspan="4">Description</th></tr>
<tr><td>Reason to start the project</td><td colspan="3">• Reduce global emissions by 22.1 million tonnes of CO_2 by 2021
• Supporting 13 of the UN’s 17 Sustainable Development Goals
• Nesting this project within Peru’s REDD+ programme means that the retired carbon credits, even internationally transacted ones, are not double counted.</td></tr>
<tr><td>Start date</td><td colspan="3">May, 2018 (Peruvian Amazon & Ben and Jerrys)</td></tr>
<tr><td>Preconditions
assumed before starting</td><td colspan="3">• Assumes forest conservation through the Cordillera Azul project bridges the emissions gap
• The solution needs to be connected to the company’s (Point of Sale) POS system</td></tr>
<tr><td>Introduction
objectives, preparations</td><td colspan="3">• Addresses the social and environmental cost of any product or service purchase
• Objective is to apply technology to drive behavioural change by empowering retailers to transform their customers’ engagement with their carbon footprint</td></tr>
<tr><td>Procedure
which steps were taken</td><td colspan="3">• May 2018; project live
• 2019; Top contributors invited to forest conservation project
• Poseidon Mobile App v3 Release</td></tr>
<tr><td>Results
or success scenario when still in progress</td><td colspan="3">• Reduce global emissions by 22.1 million tonnes of CO_2 by 2021
• Supports 13 of the UN’s 17 Sustainable Development Goals
• 73% of Ben and Jerry’s consumers in London offer to pay more than the minimum of 1 pence.
• In 2019, 3 clients had moved onto the Poseidon platform (Ben & Jerry’s, BAC, Vivobarefoot) realizing real-time bi-directional traceability to understand which carbon credit went to which emissions</td></tr>
<tr><td>Conclusions</td><td colspan="3">The solution provides the ability to transact grams of carbon fast instead of carbon transactions in tonnes of grams (traditional carbon credit certificate process). Current status in 2020 is not well documented.</td></tr>
<tr><td>Follow-up activities</td><td colspan="3">Poseidon aims to scale up their solution. With 20% of the retail market on board, the global carbon emission</td></tr>
<tr><th colspan="4">Organizational</th></tr>
<tr><td>Potential business benefits from blockchain use</td><td colspan="3">Track and manage their carbon footprint through an app that connects consumers and retailers, and allows them to see the carbon footprint of every purchase they make, and then offset it by buying carbon credits.</td></tr>
</table>

	Accountability, responsibility and transparency for everyone involved.
Potential governance benefits from blockchain use	Decentralized tracing of carbon emissions forward to the product comes with the benefit of trust in the value chain partners. Consumer has an interest in the value generated in the network.
Special concerns *political, environmental, social, technical, economic, legal, etc.*	• Adding the cost of the carbon credits required to cover the carbon footprint of the production of the item to the end consumer's bill • 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 *incl. short motivation for this choice*	Stellar blockchain, forked from Ripple Using AI and blockchain, Poseidon can quickly analyse the carbon footprint of any product or 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, hybrid)	Public 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 techniques *e.g. IoT, QR, RFID, LoRa, etc.*	N/A
Connection with existing databases/systems/ERPs	Retailer POS (Point of Sale) system Amazon Web Services infrastructure RESTful API called Horizon for Poseidon software modules
Open-source software being used/proposed	Stellar Core is open-source backend for storing and moving money
Links to related information *incl. technical white papers*	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/ 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-government-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 *max. 1-2 sentences*	The main goal of TreeCoin is to make the world greener through encouraging 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
	Local tree grower	Private	Grower

Description	
Reason to start the project	- Unsustainable deforestation - Sustainable timber production
Start date	2018
Preconditions *assumed before starting*	- Availability of fallow land in Paraguay - Fast-growing trees - Investment needed
Introduction *objectives, preparations*	- Creating digital trust by improving efficiency, transparency and payment settlement - Piloting blockchain
Procedure *which steps were taken*	- Research on the ground with local partner - Developing platform and blockchain protocol - Finding launching user - Partnering with La Rivera retail network - Hybrid Token Offering (HTO)
Results *or success scenario when still in progress*	- plant over 10 million trees in Paraguay during its initial stage of the plantation, covering more than 12 000 hectares of land in the process
Conclusions	Blockchain can be used to facilitate reforestation and sustainable timber production three traded tokens
Follow-up activities	Ongoing reforestation, timber production and natural conservation activities
Organizational	
Potential business benefits from blockchain use	- Tradable asset - Dual tokens (security and payment) - Flexibility in buying and trading earnings in tokens
Potential governance benefits from blockchain use	Transparency, accountability (auditability of transactions and trees planted) and easier management
Special concerns *political, environmental, social, technical, economic, legal, etc.*	N.A.
Technical features	
Used blockchain framework *incl. short motivation for this choice*	Ethereum, easy deployment with smart contract. Maturation of crypto assets
Type of blockchain (public, private, hybrid)	Public
Type of consensus algorithm used	ERC20 Smart Contract
Use of smart contract	Yes
Use of tokens	Hybrid coin (TREE/TXC)
Use of any special hardware or techniques *e.g. IoT, QR, RFID, LoRa, etc.*	N/A

Connection with existing databases/systems/ERPs	N/A
Open-source software being used/proposed	N/A
Links to related information *incl. technical white papers*	https://tree-coin.io/wp-content/uploads//2020/07/White_Paper_2020-07-11_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

Table 10 *A list of consensus mechanisms*

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	PoB	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 11 *A list of most used blockchain frameworks in blockchain applications*

Blockchain framework	Year of establishment	Ledger type	Code governance	Language	Cryptocurrency	Consensus mechanism	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
IOTA	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

Table 12 *Actors in a blockchain ecosystem*

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.	PPP
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

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 connection	**Portal**	API connection	Portal	**API connection**	SharePoint, OneDrive, Google 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 second)	very low	low	**high**	very high	low	**medium**	medium
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 high	**very low**	high - very high	very low	**high - very high**	N.A.
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

To explore
the potential
of nature to
improve the
quality of life

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

ISBN 978-92-5-133920-6

9 789251 339206
CB3495EN/1/03.21