Platform for Big Data in Agriculture

Blockchain For Food

Making Sense of Technology and the Impact on Biofortified Seeds

Marieke de Ruyter de Wildt | Menno van Ginkel | Kirsten Coppoolse | Bart van Maarseveen | Jenny Walton | Gideon Kruseman

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Community of Practice on Socio-economic Data Report CoP_SED-2019-003

A Platform for Big Data in Agriculture COMMUNITY OF PRACTICE

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About the CGIAR Platform for Big Data in Agriculture

The CGIAR Platform for Big data in Agriculture aims at using big data to solve agricultural development problems faster, better and at greater scale. Data has become a valuable global commodity, but it is much more than simply information: in expert hands, it is intelligence.

Already, analysts are finding ways to turn big data — the immense stocks of information collected in computers worldwide — into an invaluable resource for planning and decision-making. It is helping accelerate the development of robust responses to some of the most pressing challenges of our time: climate change/variability, food insecurity and malnutrition, and environmental degradation. The smart and effective use of data will be one of the most important tools for achieving the United Nations' Sustainable Development Goals. Big data represents an unprecedented opportunity to find new ways of reducing hunger and poverty, by applying data-driven solutions to ongoing research for development impact.

About CoP_SED

The Community of Practice on socio-economic data (SED-CoP), led by CIMMYT, aims at bringing together CGIAR centers, academia, not-for-profit research and development organizations and private sector partners willing to tackle major issues related to socio-economic data.

The community works together on strategies to make the data interoperable, in order to enhance the impact and the use of CGIAR-related socio-economic data for partners in development.

This space can be used as a discussion area, share and request relevant information and contribute towards building the community as a whole.

Citation

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License

Foreword

In the summer of 2017 Marieke de Ruyter de Wildt started a movement in the Netherlands around blockchain for food. During the first Big Data Convention in Cali Colombia in September 2017, the Community of Practice on Socio-economic Data started a working group on this topic focused on low and middle-income countries known as *The Blockchain Coalition*.

The collaboration between the Fork and CGIAR has further strengthened over the recent years with the Strike Two Summit events organized by the Fork in which the CGIAR Platform for Big data in Agriculture sits on the governing bodies.

In the past years (2017-2019), *The Blockchain Coalition* has undertaken a number of efforts to identify and develop proofs of concepts and pilots for the use of digital trust and transparency technologies of which blockchain technology is a key component.

Therefore the current report is timely to set the scene and provide insights into a specific use-case.

December 2019

Gideon Kruseman, community of practice on socio-economic data coordinator

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Management Summary

The global food system is under pressure and is in the early stages of a major transition towards more transparency, circularity, and personalisation. In the coming decades, there is an increasing need for more food production with fewer resources. Thus, increasing crop yields and nutritional value per crop is arguably an important factor in this global food transition.

Biofortification can play an important role in feeding the world. Biofortified seeds create produce with increased nutritional values, mainly minerals and vitamins, while using the same or less resources as non-biofortified variants. However, a farmer cannot distinguish a biofortified seed from a regular seed. Due to the invisible nature of the enhanced seeds, counterfeit products are common, limiting wide-scale adoption of biofortified crops. Fraudulent seeds pose a major obstacle in the adoption of biofortified crops.

A system that could guarantee the origin of the biofortified seeds is therefore required to ensure widespread adoption. This trust-ensuring immutable proof for the biofortified seeds, can be provided via blockchain technology.

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1. Why Blockchain for food

The global food system is under severe pressure as humanity's population is expected to rise to nearly **10 billion people by 2050**[1] while current dominant agricultural practices are unsustainable. With agricultural land expansion reaching its limits[2], humanity must increase agricultural productivity to feed this growing population while reducing resource usage. Moreover, climate change is bound to change crop suitability in different regions[3]. Extreme weather events threaten food supply, requiring sufficient buffers and hence higher production in favourable years.

Additionally, **urbanization** and increased welfare is changing diets and food systems. The UN DESA expects the global urban population to rise from 55% in 2018 to 68% in 2050[4]. Furthermore, people buy more processed foods[5] and **value chains are getting longer**[6], leading to vagueness of food origin. Lastly, the distance between commodity and food is growing. In many countries in the world, a double burden of malnutrition can be witnessed with an increase of **obesity and hidden hunger**[7]. The growing global population, with urbanization and malnutrition, increases demand for changes in food systems and value chains in terms of more circular practices, transparency, and personalized nutrition.

To stay within planetary boundaries, **more production has to be attained with less resources**[8]. There is a need for more efficient water and fertilizer usage, less use of crop protection chemicals that are also a hazard to biodiversity and/or human health, no deforestation, and improved management of soil resources. Currently, sustainable intensification practices are not valued because environmental and societal values are not priced. These values are invisible in commodities and agrifood at large. **Making the invisible values visible**, is a necessary pre-condition for achieving the much-needed food transition.

[1] United Nations Department of Economic and Social Affairs. (2019). World Population Prospects 2019: Highlights. Retrieved from un.org

[2] FAO. (2011). Looking Ahead in World Food and Agriculture. Chapter 6: The resources outlook: by how much do land, water and crop yields need to increase by 2050? Retrieved from fao.org

[3] Ramirez-Villegas J. & Thornton, P. K. (2015). Climate change impacts on African crop production. CCAFS Working Paper no. 119. Retrieved from cgiar.org

[4] United Nations Department of Economic and Social Affairs. (2018). World Urbanization Prospects: The 2018 Revision. Retrieved from un.org

[5] Kearney, J. (2010). Food consumption trends and drivers. *Philosophical Transactions of the Royal Society B*, 365(1554): 2793–2807. doi: 10.1098/rstb.2010.0149

[6] International Fund for Agricultural Development (2016). Rural Development Report. Chapter 6: Agrifood markets and value chains. Retrieved from ifad.org

[7] FAO, IFAD, UNICEF, WFP & WHO (2019). The State of Food Security and Nutrition in the World 2019. Safeguarding against economic slowdowns and downturns. Retrieved from fao.org

[8] Raworth, K. (2017). Doughnut economics: Seven Ways to Think Like a 21st Century Economist.

The traditional approach of increasing agricultural productivity through genetic gains is arguably insufficient to meet the future demand. **Closing existing yield gaps** can be a viable approach, especially in low and middle-income countries where this yield gap is substantial[9]. Closing the yield gap has proven very daunting. The agricultural technologies to do so exist, but require overcoming serious challenges linked to market failures, institutional arrangements and governance structures. Moreover, agriculture is a risky business for farmers. Farmers face environmental risks in terms of increasingly uncertain weather conditions, but also serious market risks. It is no surprise that agricultural decision-making equals risk management. If market-related risks, associated with the use of existing agricultural technologies that have been tried and tested, could be substantially diminished, it is possible to close part of the yield gap.

Within the research community, it has been proposed that **biofortification may contribute to close part of the yield gap**[10]. Biofortified seeds are seeds with higher nutritional values like vitamins and minerals, gained by natural selection. However, bio-fortified food cannot be distinguished from non-biofortified in terms of appearance or aromas. Like with the occurrence of toxins such as aflatoxins, it is an unseen characteristic. Being able to **ensure trust in the presence or absence of invisible characteristics**, can contribute to improving yield gaps and meeting the nutritional demand of tomorrow.

Low and middle-income countries are becoming part of data-driven industrial revolution. The internet of things (IoT), robotics, earth observation and remote sensing are increasingly being used to close the yield gap. Data related to farmers, their livelihoods and their enterprises are being collected without farmers having control. Others often know more about the farmers and their farms than they do themselves. A future-proof food transition requires **data systems where farmers are in control of their data**, where they can determine how that data is shared.

It has been argued that **blockchain technology is a fundamental technology** for facing the aforementioned food challenge[11]. It can help re-value food for its true value, help address market failures, proof invisible characteristics, arrange data ownership and nourish data-sharing models. Companies like Cargill, Nestle, Nutreco, Whole Foods, Walmart and Carrefour are increasing their investments in this technology[12]. Equally interesting are emerging supply-chain broad consortia that start using these decentralized technologies[13]. Technologies that have rules without a single ruler, where power is decentralized and allocated to all users. This is blockchain technology. As this

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[9] Pradhan P, Fischer G, van Velthuizen H, Reusser D. E. & Kropp, J. P. (2015). Closing Yield Gaps: How Sustainable Can We Be? *PLoS ONE*, 10(6). doi: 10.1371/journal.pone.0129487

[10] Bouis, H. & Saltzman, A. (2017). Improving nutrition through biofortification: A review of evidence from HarvestPlus, 2003 through 2016. *Global Food Security*, 12: 49–58. doi: 10.1016/j.gfs.2017.01.009

[11] Tripoli, M. & Schmidhuber, J. (2018). Emerging Opportunities for the Application of Blockchain in the Agri-food Industry. Retrieved from fao.org

[12] Kuhn, D. (2019). Nestle Announces New Blockchain Initiative Separate From Ongoing IBM Project. Retrieved from coindesk.com

[13] IBM. (2018). Focus on Supply Chain Efficiencies. Retrieved from ibm.com

technology is enriching other key markets like financial markets, it is also enriching agrifood. **This guide aims to be real about the value of blockchain for agrifood today, and help you define its value for your work**.

2. Why this guide

The global food industry is in transition towards **more transparency, circularity and personalization**. There is a wide range of technologies that enable this transition, and blockchain is a recent and promising digital tool to solve problems in agrifood. In the case of using biofortification to close the agricultural yield gap, the main problem for adoption of biofortified seeds can be contributed to the lack of trust and traceability of the biofortified products in the value chain[14]. In other words, it is difficult to verify the authenticity of biofortified products due to common practices of counterfeiting and blending. Thus, the central question of this technical note is formulated as follows: *How can blockchain technology be leveraged to prevent counterfeit and blending practices from the value chain of biofortified seeds?* In order to answer this question, various sub-questions require answering first:

- What is the value chain ecosystem of biofortified products?
- What are the current approaches to prevent counterfeit biofortified products in this ecosystem?
- What are the unique aspects of blockchain technology that help solve the problem of counterfeit biofortified products?

Gaining a better understanding of these topics creates opportunities for new pilot programs to verify the claims made in this technical note in practice.

This paper dives deep into blockchain technologies, presenting an overview of this emerging innovation, including the relevance for the agrifood sector in general, and for organizations that strive for future-proof food systems, like HarvestPlus.

In November 2018, Jenny Walton (HarvestPlus) contacted Jan van Iperen (The Fork), referring to an article Jan had published on LinkedIn[15]. Jenny Walton wanted to understand if blockchain could be of value to their organization. In January 2019, the community involved in The Food Integrity Blockchained Meetup, decided to help HarvestPlus[16] in addressing its fundamental challenge: how to unleash the commercial market for biofortified seeds by overcoming the fundamental problem of authenticity by leveraging blockchain technology.

During monthly live recorded check-ins with the community[17], The Fork[18] and HarvestPlus gave updates on the progress of the project and received help from the community. Design topics were addressed, from how to find funding for blockchain projects to the physical-digital disconnect. The Fork presented parts of the technical note and explained choices for an open and public blockchain.

[14] J. Walton, personal communication, September 25, 2019
[15] Van Iperen, J. (2017). Calling all Food & Beverage Geeks! Retrieved from linkedin.com
[16] harvestplus.org
[17] Youtube: youtube.com/channel/UCsyBw9YNtg9KVm_XUgjW6jA
[18] thefork.online

Some domain aspects were addressed, like the concept of biofortification. During this process, it became clear to all of us that this hands-on, open-sourced experience was very valuable to many people working in agrifood. Additionally, six interviews have been conducted with experts in this industry, from farmers to researchers, and from nutritional marketeers to blockchain architects. This document documents our journey and aims to explain the fundamental design choices in the hope to help and inspire others that face similar challenges.

3. Why Blockchain

Many of the wicked problems and seemingly insuperable challenges facing dynamic complex agri-food systems, especially in low and middle-income countries, boil down to a lack of trust, transparency and unreliable governance structures. We have seen examples where the smart use of blockchain can help mitigate these issues. Even specifically focussed on the authenticity of seeds the possibilities of blockchain technology are already being explored by other parties, like the department of Agriculture and Welfare in Punjab.[19]

Many people associate blockchain with the bitcoin, but to understand this novel technology's impact on agrifood it is much more valuable to go to its roots[20]. Blockchain technology is an emerging **general-purpose technology platform**, like artificial intelligence and robotics[21]. A general-purpose technology serves as a base-layer for the creation of other innovations and can therefore have a major impact on society. It is essentially a basic data infrastructure and therefore it matters for agrifood.

Some examples of the last century include steam-engines, electricity, computers, and the internet. Similar to these well-known and world-changing innovations, blockchain technologies can be applied to a wide range of existing industries and enables the creation of new businesses, niches and sectors.

Blockchain allows *global frictionless value transfers* as well as *maintenance of shared information among mutually mistrusting actors* without the need to trust a third party. This technical explains what these two things *really* mean further down. For now, blockchain enables new types of collaboration by combining data technology with network technology.

Technically, blockchain is a new immutable and chronological data structure that enables **a network of untrusting actors** to maintain **shared information** and reach consensus about the **validity** of that information, without an intermediary. Following quotations express the essence and relevance of this technology:

[19] PotatoPro (2019). Punjab to introduce seed potato tracebility and certification using blockchain technology. Retrieved from potatopro.com

[20] Haber & Stornetta (1991). How to time-stamp a digital document. Retrieved from springer.com

[21] Winton, B. (2019). Disruptive Innovation: Why Now? Retrieved from ark-invest.com

"In general, using an open or permissioned blockchain only makes sense when multiple mutually mistrusting entities want to interact and change the state of a system, and are not willing to agree on an online trusted third party"[22].

"Or, to put this in a gentler way, those parties work together but don't have completely aligned interests—for example, manufacturers, shippers, and buyers tracking goods along a supply chain, where some parties might have an incentive to fudge on when things were delivered—or, worst case, swap in counterfeit goods"[23].

Traditional **relational databases** structures data in rows and columns. These databases also allow shared information management for collaborative purposes. In a shared spreadsheet environment in the cloud, such as Google Suite or Microsoft 365, every participant can view, add, edit and delete data. The issue in these collaborative data systems is that anyone can delete and edit the history, which can lead to unknown and unwanted changes to the collective dataset. Additionally, the data is stored in a datacentre managed by a central entity that can be hacked, that can revoke access, sell user data, or provide sensitive information to authorities or media outlets. These characteristics of collaborative relational databases are not desirable in a range of situations, especially in agrifood where it is essential to be able to trust information.

Enter blockchain technology. Data in a blockchain is not structured in rows and columns. Instead, data is chronologically packaged in **timestamped blocks** that link to each other via fancy math known as cryptography. Every time new data is added to this collaborative unidirectional database, or **distributed ledger**, the actors in the network verify and agree that this new information is correct before packaging this data into a new block and adding it to the blockchain. The new state of the blockchain is **simultaneously updated** by every participant in the network, so everyone has the latest version at the same time. Appendix 1 provides a more detailed explanation of this process in a transaction cycle. Once a block with data is added to the blockchain it **cannot be changed**, as that would require to change all the linked data blocks in all the participants' copies.

Even though this novel **networked data system** is commonly much slower and more expensive to use than a traditional relational database, the benefits of using a blockchain can be worth the trade-off for certain applications. It can be argued that there are **three main benefits** of utilizing blockchain technology over traditional relational databases in the agri-food sector[24].

1. To create an immutable and transparent data record.
2. To register and fractionalize ownership of assets.
3. To have collaborative relationships and rules without a ruler.

[22] Wüst, K. & Gervais, A. (2017). Do you need a Blockchain? Retrieved from eprint.iacr.org (p. 2)
[23] Murphy, C. (2019). Why Do I Need Blockchain If I Have A Database? Retrieved from www.forbes.com
[24] de Ruyter de Wildt, M. (2018). #Agblockchain: values and fallacies. Retrieved from ictupdate.cta.int

These benefits, explained in more detail below, can contribute to a transparent trust system and a level playing field, increasing food safety and encouraging fair distribution of profits along food supply chains.

3.1. Immutable and transparent record of events

Data blocks on a blockchain are chronologically generated and timestamped, linked together via fancy math, and simultaneously updated for every network actor. This makes the information stored on this collaborative dataset unhackable and immutable. Thus, a shared truth between participants is created. The base of this shared truth comes from trust in code and math instead of a third party. Depending on what type of blockchain is used, data on a blockchain can be open and publicly available, enabling a transparent record. An immutable and transparent record of events can be desirable for tracking products in a supply chain.

3.2. Self-owned and managed data

Ownership of a particular asset is usually registered and controlled by a central authority, whether it be ownership of a company, real estate, financial assets, a piece of land, a car, one's identity, or some data. Within the agricultural and food industry, paper-based registration of transactions is still common in some parts of the supply chain. Moreover, processes that are digitalized often result in data silos and non-communicating IT systems, creating obstacles for innovation and collaboration[25]. Blockchain technologies enables stakeholders to control, manage and share their own data, independent of the service or application that generated it, and without a single point that acts as a gatekeeper which can blur ownership rights. Data sharing among supply chain actors can thus become easier, incentivized and rewarded. Data integrity is of great importance for the agri-food sector as it is directly connected to food safety. Blockchain technologies allows mutually mistrusting actors to own their data and share some of it with other parties, breaking down data silos in the food transition.

Additionally, blockchain technology allows multiple actors to have shared or fractionalized ownership of an asset through tokenization. This can be useful for cooperative organizations, community owned farms, collective usage of agricultural machinery, or shared investments into a new joined venture. Fractionalized co-ownership can lead to new business models and collaborative action in the agri-food industry.

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[25] Baker, P. (2019). Blockchain food supply chain growth depends on clean data. Retrieved from searcherp.techtarget.com

3.3. Rules without rulers

It can be desirable that no single party is able to exercise more influence in a collaborative network, especially regarding the state of shared truth or the rules for collaboration. Blockchain networks are distributed systems and can consist of thousands, potentially millions, of mutually mistrusting actors. The rules to interact, contribute and collaborate in this network are written and stored into computer code. This software is peer-reviewed and, when sufficiently tested and verified, run by all actors in the network. So instead of trusting a select group of corruptible humans with the authority to enforce these rules, the trust is based on collective efforts to program these rules into a piece of software, which are automatically enforced.

In other words, trust among mutually mistrusting actors is based on open-source, peer-reviewed and thoroughly tested math and code, making trust programmable. Since this coded trust is run by a distributed network of participants, it is resilient against corruption. Therefore, there can be rules without a ruler in a blockchain-based collaborative network, which can make collaboration in food supply chain networks manipulation proof and censorship resistant, as well as fair and transparent.

4. What is blockchain

Blockchain is a networked data infrastructure with build-in programmable trust, that enables trustless collaboration among mutually mistrusting actors by verifying, timestamping, and synchronizing inputted data. A blockchain network can be permissionless or permissioned, while hybrid systems are also possible.

A permissionless blockchain refers to the idea that no permission is needed to join the network of shared data; participation is open for everyone.

A permissioned blockchain refers to a network for which an actor needs permission to participate; it is a closed collaborative environment.

Appendix 2 provides more details about the differences between permissionless and permissioned blockchains.

Either blockchain type can publish the shared data publicly or privately. A hybrid combination, in which some data is private while other data is public, is also possible.

In this paper, however, blockchain is defined as an open and networked data structure, in which participants are free to join or leave. Data stored on these blockchains is immutable due to cryptographic protocols that disallow data entry history to be reversed. This means that in blockchain acts as a decentralized network, where all data are shared with the entire network.

There is not one open public blockchain, there are many blockchain solutions in existence, with different names and properties. Some of these blockchains can communicate with each other, which is called interoperability. Interoperability is an important factor to consider when selecting a blockchain solution.

More extensive information on what blockchain technology is en how it works, can be found in the appendix.

5. Blockchain for agrifood

The agricultural sector and food systems consist of complex webs of networks, where most participants do not trust each other. As mentioned, blockchain is only relevant when mutually mistrusting actors need to share data, such as transactions, and do not want to rely on a third party to provide trust between the network participants. In practice, this relates to many situations in agrifood.

First, when there are **inefficiencies** in transactions in terms of lead time and expenses. The most obvious example is in **finance**, supply chain finance or microfinance where blockchain is transforming the industry. AgriWallet is a great example.[26] **Insurance** products for the agrifood sector are an example. An automated blockchain-based smart contract can result in faster and cheaper pay-outs if a certain insurable condition has provably occurred. Fizzy is already around for several years and it is easy to understand how this can be applied to food.[27] Another large area is the **compliance** to norms and standards, from government or private parties. This refers to certification and involves standard setting agencies, auditors, farmers, processing and retail companies and end-consumers. FairChain is an illustrative example.[28]

Second, sometimes **independent third parties are lacking**, cannot be trusted, or the proof provided by such parties may go missing. In this context, the **registration of agricultural land** ownership is an area where blockchain can add value.[29] It is often paper based, or not officially registered at all. Another example is at weak **border controls,**[30] where there is notice of bribery or governance that works with limited resources. Via smart contracts, checking agrifood for eligible import can be made more effective.

Third, when there can be **benefits from a networked** data infrastructure, as for example in the case of **provenance, traceability and recall** of food products. VeChain, initiated by the CTO of Louis Vuitton, is one of the most comprehensive examples.[31] Actors in the supply chain may have incentives to falsify product information, which can lead to issues in food safety and quality. In a digital system where supply chain actors **share and verify data**, these fraudulent types of behaviour can be disincentivized by creating a digital passport of a physical product. In this passport, all the events that are relevant for proofing the origin, quality and safety of a product can be recorded – including soil quality, climate conditions, certifications, logistical information, and nutritional values.

[26] agri-wallet.com
[27] fizzy.axa
[28] fairchain.org
[29] Kriticos, S. (2019). Keeping it clean: Can blockchain change the nature of land registry in developing countries? Retrieved from blogs.worldbank.org

[30] Accenture (2019). Bridging borders with blockchain. Retrieved from accenture.com
[31] vechain.com

When proving origin or quality of the food product, the digital passport should contain all the necessary and immutable data. By using blockchain technology, this data passport is made 'append only', referring that information about the product is stored chronologically. If some actor has falsified product information and somehow managed to pass it through the verification process, the **fraud will be forever registered** in the blockchain network, which may lead to sanctions in the future.

Fourth, there is a very promising and new application of blockchain in the agri-food industry, leveraging the technology's capability of **frictionless micro value transfer** that provides very new business models. One example is **new ownership models**. With blockchain applications like Stem[32] employees but also neighbours and consumers can start participating in the farm. Shared ownership of or co-investing in a farm or agricultural machinery can be enabled by blockchain technology, spreading the risks and rewards of these assets among the participants. Machine-to-machine interactions in the 'Internet of Food'[33] paradigm may require payments directly from one device to another. Machines are excluded from utilizing bank accounts provided by traditional financial institutions but can leverage cryptocurrencies and digital wallets to enable this type of desired interaction. Tokenization of assets can lead to novel ways of exchanging value. Another very promising area is **tradeable CO_2 certificates**. Soil passports that indicate the level of CO_2 capture can be registered on a blockchain, and if aggregated across farms, can reach volumes that can be tradable.

The examples described above merely illustrate the most obvious use-cases in blockchain for food. Other applications are likely to emerge as blockchain technology matures.

[32] stemapp.io

[33] The EU funded project Internet of Food & Farm 2020 (IoF2020) explores the potential of IoT-technologies for the European food and farming industry. See https://www.iof2020.eu/about for more information.

6. Use Case: Biofortified Seeds Nigeria - blockchain for fortified maize

HarvestPlus is a non-profit organization that is developing and promoting new, more nutritious varieties of staple food crops with higher amounts of vitamin A, iron or zinc—three of the micronutrients identified by the World Health Organization as most lacking in diets globally. The process is known as biofortification. Regular consumption of these innovative crops is improving nutrition and public health.

HarvestPlus needed to better understand the barriers to widespread adoption of biofortified foods. Between June 2017 and August 2018, they set upon systematically interviewing food value chain members across the globe. They interviewed nearly 100 businesses and 250 individuals about their experiences and requirements for biofortification. From the farmer, seed seller, processor and marketer. From farm gate sales to multinational, global brands. The research uncovered 4 main barriers to scale:

(1) Building a value proposition for businesses and consumers

- Opportunity to create awareness and excitement
- Drive market demand and consumer
- Understand consumer needs and interest

(2) Standards, Traceability and Regulatory frameworks

- Work with regulators and standards
- Build the best methods for supply chain traceability (identity preservation or authenticity preservation)

(3) Route to market: value chain development

- Link large food and ingredient suppliers

(4) Lack of awareness of HP delivery experience and expertise

- HarvestPlus must communicate its experience

HarvestPlus concluded that if they would work together with partners, donors and the food industry, they could collectively scale up and embed biofortification into the food system. It was about setting standards, traceability and regulatory frame works: they needed to build the best methods for supply chain traceability (identity preservation or authenticity preservation). The stakeholder research revealed that one of the biggest barriers for the food industry to adopt biofortification is the inability to distinguish biofortified crops from standard. If it is not possible to differentiate the foods, protect and verify the identity across the supply chain, the added value cannot be communicated to the customer or consumer. Given the value that biofortification can bring, there are increasing incidents of food fraud at seed and food level. This problem, or market failure, is an excellent example where there are benefits from a **networked data infrastructure**.

A networked data infrastructure can also help with several other issues such as

1. Food safety and aflatoxins
2. Better monitoring and evaluation techniques – the ability to accurately quantify amounts of biofortified crops
3. Technology in the hands of HarvestPlus – demonstrating leadership in the commercialization of biofortified foods

Mintel, a global market research company, identified traceability as one of the five most important food and drink trends for 2018. Traceability is then understood as the ability to see where food comes from, what it's made with, and by whom. According to Mintel, the trend is fuelled by "widespread distrust" in how our food is made, the "need for reassurance about the safety and trustworthiness" of food, and the increasing use of natural, ethical and environmental claims on packaging.[34] Other consumer research points out that over half of consumer purchases are driven by health, safety, social impact and experience—all of which require transparency and traceability.

HarvestPlus sought a partner in this area and evaluated options available. The Fork was identified as a partner with the following advantages:

1. Leading experts and ability to train people in usage an understanding technology
2. Small and nimble: able to adapt to specific problems and projects, speed of innovation
3. Experience and background in international development: willing and available to join fundraise for projects
4. Supportive and collaborative: sharing knowledge and tools. Excellent support network
5. Available: with offices in both The Netherlands and DC, always available for contact and support

Following discussions, HarvestPlus and The Fork started to collaborate to investigate solutions to protect the authenticity of biofortification across and throughout the value chain.

They are developing the solution on a public open blockchain. This is something all interviewed experts are in favour of. Brian King, coordinator of the CGIAR[35] Platform for big data in Agriculture,

[34] Mintel (2017). Mintel Announces Five Global Food and Drink Trends for 2018. Retrieved from mintel.com

[35] cgiar.org

calls for open standards and interoperability in order to *"drive down the cost of innovation".*[36] Chris Addison, CTA[37]'s Coordinator Knowledge Management points out that the open sources aspect of open blockchain makes it possible to use third party API's, which makes it possible for people from outside the Biofortified Seeds Nigeria use case to contribute.[38]

Another argument for open public blockchain is that this way no party can control the whole supply chain. Bart van Maarseveen, Blockchain architect at The Fork, sees open public blockchain as an empowerment tool for the whole supply chain. Farmers and other supply chain actors don't need permission to join the blockchain network. Therefore, the blockchain can't be controlled by one powerful party within the supply chain.[39] Henk van Cann, Blockchain Architect at Blockchain Workspace[40], sees the risk of traditional investors trying to take over a new solution, which could lead to a new solution changing into business as usual.[41] In order to really change and innovate supply chains blockchains have to be decentralized and therefore open and public.

They are prioritizing the following crops and countries to start implementing:

1. Nigeria Vitamin A Orange Maize
2. India zinc wheat
3. India zinc rice
4. India iron pearl millet

[36] B. King, personal communication, September 19, 2019

[37] cta.int

[38] C. Addison, personal communication, September 25, 2019

[39] B van Maarseveen, personal communication, September 20, 2019

[40] blockchainworkspace.com

[41] H. van Cann, personal communication, September 19, 2019

7. Technical roadmap

It is difficult to provide a detailed technical roadmap at this stage, as this depends on the specifics of the desired product and possible new developments within blockchain technology. So instead of presenting the technical roadmap here, the process of producing such a roadmap is described below. The project follows the criteria outlined by Principles for Digital Development.[42]

What

1. *Analyze the supply chain*
   Supply chain analysis, resulting in a process description of all the steps in the supply chain, including all actors and stakeholders. The expected volumes and speed of the supply chain over time should be analysed as well. We want to avoid working based on assumptions therefore, it's important check with the stakeholders on to verify if this project addresses their challenges.
2. *Identify the practices*
   Identifying the data that is generated in each step and choosing what is relevant for proofing provenance. This results in a datasheet for each actor in the supply chain, noting what is public and what is private data. The actions of each supply chain actor are also identified.
3. *Governance model design*
   Define what type of governance is needed to reach the defined goals, including various node types and the distribution of decision-making power.

How

4. *Token model creation*
   Design a token model to incentivize the desired behaviour of all the participants in the network, and thereby implementing the governance model. The result will be a document describing the rules for token creation, distribution and burning tokens as well as the economic functions of the designed tokens.
5. *Design the technology*
   The global technical solution is designed during a workshop. Various parts of the blockchain architecture are defined and prioritized into potentially buildable components. This step results in a global design document, a technology stack describing the total solution, including important aspects as security, scalability, interoperability, and layering.

[42] digitalprinciples.org

6. *Charting*
   The technology that shall be used is identified, as well as the required milestones and the resources. The result of this step is the first version of the technical roadmap.

How could the smallholder farmer engage?

For a smallholder farmer to be able to use blockchain technology, the first step would be access to a phone. Ideally this would be a smartphone (including internet access), but the Biofortified Seeds Nigeria use case can also explore the use of SMS. In the case of smartphone use, the farmer would use an app to scan a QR-code on a bag of seeds he or she's planning on buying. The farmer then sees the complete journey of the sealed bag of seeds, showing him the product is authentic and untampered with. Immutable QR-codes like used by ScanTrust[43] prevent QR-codes being switched around.

Principles of Digital Development during the Biofortified Seeds Nigeria use case

1. *Design with the User*
   In order for the Nigerian supply chain actors to successfully use a blockchain application, human centric design is a big criterium. One of the people involved in this project is Ben Ekanikpong of El-kanis and partners[44], FarmX[45] and The Fork, as a Nigerian farmer and the creator of a farm management app, he is uniquely qualified to give input on the requirements of the user and connect the project to more local users, if needed, since he has an extensive network of farmers, service providers and local government. Ben Ekanikpong recommends using the AID[46] model for stakeholder involvement for the Biofortified Seeds Nigeria use case. According to him awareness can be created by different types of online and offline marketing, including talks in town hall meetings. For the next step, building interest, he recommends using the POC. Try-outs, demos, training and trials are a tangible way for stakeholders to experience the solution and get an idea of its benefits.[47] Chris Addison also sees raising awareness and then training the users as the important step to follow when rolling out the Biofortified Seeds Nigeria use case.[48]

[43] scantrust.com
[44] elkanisgroup.com
[45] elkanisgroup.com
[46] Awareness, Interest, Doable
[47] B. Ekanikpong, personal communication, September 19, 2019

[48] C. Addison, personal communication, September 25, 2019

Of course, there is also the technological realities of the user to consider when designing the Biofortified Seeds Nigeria use case. Ben Ekanikpong names availability of power and internet connection and the cost of data as aspects to address when aiming for successful adoption. He further recommends starting with simple technology like mobile apps, USSD and or SMS and possibly voice response and support of the local dialect.[49]

Important to consider is that currently not all smallholder farmers are (smart)phone users. In 2018 about 70% of Sub-Saharan Africa was covered by 3G.[50] About 95% percent of Sub-Saharan Africa is covered by 2G and 3G is rapidly catching up, while there are mayor investments in rolling out 4G.[51] However, there are still many farmers in Nigeria that don't have a stable internet connection.[52] One of the ways that to solve lack of connection to the internet is creating SMS access to the blockchain. This is something that multiple blockchain provides are currently working on.

Nigeria has one of the most active mobile solution for agrifood markets in Africa.[53] Therefore, the idea of using mobile phones in farming practises is not foreign here. Even blockchain technology for farming is not new in Nigeria. Binkabi[54] is, for example, active in Nigeria.[55]

2. *Understand the Existing Ecosystem*
   The partners in this project have both experiential and researched knowledge of the existing ecosystem. Both the agrifood system in Nigeria as the blockchain ecosystem. Harvest Plus has many years of experience working in Nigeria and promoting biofortified seeds in Nigeria and other areas of the world. CGIAR is a leading organisation in the fight against hunger. The Fork is specialized in blockchain for agrifood and active in the blockchain ecosystem for more than 2 years. Chris Addison also recommends identifying extra partners in Nigeria that are trusted by the farmers, for example farmers unions.[56]

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[49] B. Ekanikpong, personal communication, September 2, 2019

[50] Bahia, K & Suardi, S. (2019). Connected Society: The State of Mobile Internet Connectivity 2019. (P.7). Retrieved from gsma.com

[51] Bahia, K & Suardi, S. (2019). Connected Society: The State of Mobile Internet Connectivity 2019. (P.17). Retrieved from gsma.com

[52] Tsan, M. et al. (2019). The digitalisation of African Agriculture Report 2018-2019. (P. 184). Retrieved from www.cta.int

[53] Tsan, M. et al. (2019). The digitalisation of African Agriculture Report 2018-2019. (P. 183). Retrieved from www.cta.int

[54] binkabi.io

[55] Tsan, M. et al. (2019). The digitalisation of African Agriculture Report 2018-2019. (P. 183). Retrieved from www.cta.int

[56] C. Addison, personal communication, September 25, 2019

Nigeria is the most populous country in Africa,[57] and it is one of the fastest growing economies in Africa.[58] 36.55% of Nigeria's labour force works in agriculture,[59] but Nigeria also has one of the fastest growing populations, which makes Nigeria unable to meet the consumption needs. The Maize consumption in Nigeria is predicted to rise with more than 10% between 2007 and 2027. Nigeria is also one of the worst performers in healthy diets[60] There is a need for more healthy food. Biofortified Seeds might be able to help feed Nigeria. In order to be able to use blockchain the whole supply chain should be able to access the internet. That means that farmers (and other supply chain actors) should have a smartphone and internet coverage.

In 2018 Sub-Saharan smartphone ownership was 45%[61] This number might be as low as 29% when solely focussed on Nigerian farmers. However, the Nigerian government currently has an initiative in place to provide smart phones to farmers as part of the Growth Enhancement Support.[62] Nigeria is one of the frontrunners in Africa in mobile phone and internet coverage, 75% of the country was covered by provider MNT in 2018.[63] The Barilla Centre for food & nutrition rates the quality of agricultural subsidies in Nigeria as good in their Fixing Food 2018-2019 report.[64] In the Digitalisation of African Agriculture Report 2018-2019 from Dalberg advisors and CTA it is stated that the private sector in Nigeria is investing in innovation in agrifood.[65] This might be beneficial when looking for extra partners for the Biofortified Seeds Nigeria use case. Adult literacy in Sub-Saharan Africa is 63%.[66] Therefore, it's safe to assume that a percentage of the Nigerian farmer population is illiterate. This will be taken into account when creating the UX/UI design of the blockchain solution. A possible solution, suggested by Ben Ekanikpong, is using Voice Response. An alternative that has already proven itself as a

57 Udoh, B. (2019). Agribusiness in Nigeria Fact Sheet 2019. Retrieved from agroberichtenbuitenland.nl
58 Tsan, M. et al. (2019). The digitalisation of African Agriculture Report 2018-2019. (P. 30). Retrieved from www.cta.int
59 Udoh, Brian, Agribusiness in Nigeria Fact Sheet 2019, 2019 https://www.agroberichtenbuitenland.nl
60 Barilla Center for food & nutrition (2018). FIXING FOOD 2018. (P. 19-20). Retrieved from barillacfn.com

61 Bahia, K & Suardi, S. (2019). Connected Society: The State of Mobile Internet Connectivity 2019. (P.50). Retrieved from gsma.com
62 allafrica.com
63 Bahia, K & Suardi, S. (2019). Connected Society: The State of Mobile Internet Connectivity 2019. (P.18). Retrieved from gsma.com
64 Barilla Center for food & nutrition (2018). FIXING FOOD 2018. (P. 30). Retrieved from barillacfn.com
65 Tsan, M. et al. (2019). The digitalisation of African Agriculture Report 2018-2019. (P. 181). Retrieved from www.cta.int
66 Bahia, K & Suardi, S. (2019). Connected Society: The State of Mobile Internet Connectivity 2019. (P.50). Retrieved from gsma.com

solution for the first mile is a simple smartphone application that makes use of shapes and colours, like AgUnity's[67]

3. *Design for Scale*
   After the design phase a blockchain project often starts with a Proof of Concept which is a small scale (for example just one farm) testing of the design. When the PoC is succesful the next step would be scaling up the solution. This requires that the design already considers scaling up the PoC.

   We take scaling of the solution into account in the architecture choices made in the design. An example is the selecting of a blockchain that's able to handle blockchain transactions on the required scale and taking interoperability into account, so it might be possible to connect this blockchain solution to other blockchain solutions.

   Chris Addison recommends not just focussing on the technical side of scaling up, but also on the financial side.[68]

4. *Build for Sustainability*
   In order to maximise the long-term impact of the blockchain solution, you have to think long term, therefore a sustainable blockchain solution is a scalable blockchain solution. Blockchain of course has the stigma of not being very sustainable, based on the energy consumption of Bitcoin, something that Bart van Maarseveen has addresses previously.[69] However, when designing a blockchain solution it's of course important to take energy consumption and energy sources into account.

[67] agunity.com
[68] C. Addison, personal communication, September 25, 2019
[69] Maarseveen, van, B. (2018). Bitcoin is the energy saver the world is waiting for. Retrieved from blockdam.nl

5. *Be Data Driven*
   This principle almost speaks for itself in this use case. Blockchain makes it easier to share and created trusted data, therefore enabling food producers and consumers to make informed decisions.
   A blockchain is not the same as a database, it's important to select the right data to collect and share for the Biofortified Seeds Nigeria use case.

6. *Use Open Standards, Open Data, Open Source, and Open Innovation*
   Blockchain makes data sharing easier and saver. However, that doesn't mean that all blockchains are open, currently many blockchain for food projects are created on permissioned blockchains. This principle inspires the choice for open public blockchain for the Biofortified Seeds Nigeria use case, since public blockchains are open source and open innovation. In the appendix you can find more information on open blockchains.

7. *Reuse and Improve*
   When the Biofortified Seeds Nigeria use case is successful, this solution can be replicated for other products and in other areas, for example for zinc biofortified wheat or rice in India. It also might be possible for this project to reuse part of other use cases or improve with third party API's, since the Biofortified Seeds Nigeria use case works with open source technology. That also means that other use cases can benefit from the work done in the Biofortified Seeds Nigeria use case.

   Like all IT solutions, a blockchain solution needs to be monitor for potential updates. Bart van Maarseveen calls for continuously improving the system in order to make it more robust and censorship resistant.[70]

8. *Address Privacy and Security*
   Data in the blockchain are immutable. It's not possible to change or redact them. Therefore, the Biofortified Seeds Nigeria use case is only planning in sharing product and supply chain data and no personal information of consumers and producers, since that would impact privacy. If an extension on the POC would want to share consumer data, it's important to look into Nigerian laws about privacy.

   Data-ownership is also important to address. As stated in point 5, it's important to consider

[70] B. van Maarseveen, personal communication, September 20, 2019

what data to collect, but it's also important to create consensus on who owns the data. It's important to make sure that farmers are still the owner of their own data. Data-ownership could potentially lead to an extra revenue stream for the Nigerian farmers. Security is considered in the choice of the type of blockchain. What consensus mechanism does the selected blockchain use and how secure is that? Public blockchains like Bitcoin, with a proof of work mechanism are often very secure, since it would take a lot of computing power, and therefore a lot of money, to make a successful attack on this blockchain. Another important point is connectivity. Ben Ekanikpong warns that power and internet connectivity are not always available in Nigeria.[71] According to Henk van Cann, connectivity is needed for a working blockchain implementation, but not constantly.[72]

9. *Be Collaborative*
   This is a non-rigid multi-party collaborative effort. When needed, involving extra technology partners or stakeholder interest groups is certainly possible. One of the questions when analysing the POC is, what additional parties to involve for a further rollout.

[71] B. Ekanikpong, Personal communication, September 19, 2019
[72] Interview 19-09-2019

Further Reading

Blockchain implemented in developing countries is often thought to bring additional challenges. Some articles that discuss this:

https://medium.com/swlh/what-blockchain-means-for-developing-countries-1ec25a416a4b

https://bitcoinmagazine.com/articles/blockchains-greatest-impact-will-be-developing-countries-says-upenn-lecturer

https://www.worldbank.org/en/news/feature/2019/01/24/blockchain-como-asegurarse-que-cada-dolar-llegue-a-quien-lo-necesita

Next section provides an overview of further readings in the topic of blockchain for agriculture and food supply chains. The report by FAO is highly recommended.

Accenture (2018). Tracing the Supply Chain. How blockchain can enable traceability in the food industry. Retrieved from https://www.accenture.com/_acnmedia/PDF-93/Accenture-Tracing-Supply-Chain-Blockchain-Study-PoV.pdf

CTA (2018). ICT Update #88 Unlocking the potential of blockchain for agriculture. Retrieved from https://ictupdate.cta.int/en/issues/88-blockchain

Deloitte (2017). Continuous interconnected supply chain. Using Blockchain & Internet-of-Things in supply chain traceability. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/lu/Documents/technology/lu-blockchain-internet-things-supply-chain-traceability.pdf

Deloitte (2019). The emerging blockchain economy for food. Blockchain and radical transparency for growth in the food industry. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/us/Documents/consumer-business/us-consumer-emerging-blockchain-economy-for-food-061219.pdf

Deloitte (2019). From siloed to distributed. Blockchain enables the digital supply network. Retrieved from https://www2.deloitte.com/content/dam/insights/us/ articles/4733_From-siloed-to-distributed/DI_From-siloed-to-distributed.pdf

Fairfood & WUR (2019). A chain of possibilities: Scoping the potential of blockchain technology for agri-food production chains in low- and middle-income countries. Retrieved from https://knowledge4food.net/wp-content/uploads/2019/05/ 190515_fairfood-report_chain-of-possibilities.pdf

FAO (2019). E-agriculture in action: Blockchain for Agriculture Opportunities and Challenges. Retrieved from http://www.fao.org/3/ca2906en/CA2906EN.pdf

GFAR, GODAN & CTA (2018). Digital and Data-Driven Agriculture: Harnessing the Power of Data for Smallholders. Retrieved from https://cgspace.cgiar.org/bitstream/handle/10568/92477/GFAR-GODAN-CTA-white-paper-final.pdf

GSMA (2017). Blockchain for Development: Emerging Opportunities for Mobile, Identity and Aid. Retrieved from https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2017/12/Blockchain-for-Development.pdf

Kamilaris, A., Fonts, A. & Prenafeta-Boldú, F. (2018). The Rise of the Blockchain Technology in Agriculture and Food Supply Chain. Retrieved from https://www.researchgate.net/profile/Andreas_Kamilaris/publication/327534824_The_Rise_of_the_Blockchain_Technology_in_Agriculture_and_Food_Supply_Chain/links/5b93d0ada6fdccfd5428b0f2/The-Rise-of-the-Blockchain-Technology-in-Agriculture-and-Food-Supply-Chain.pdf

Smallholder Farmers Alliance, Impact Farming, RCS Global, Better & Timberland (2018). Concept Note: Blockchain Cotton Project in Haiti. Retrieved from

https://static1.1.sqspcdn.com/static/f/1740404/27802879/1516200937980/Concept+Note+for+Blockchain+Cotton+Project+in+Haiti+-+January+2018.pdf

Appendix 1: What is blockchain

Blockchain technology as a new general-purpose technology platform has many applications and can therefore be difficult to define. It has been argued that blockchain networks are the next era of computing platforms, after mainframes, personal computers and smartphones.[73] In this narrative, blockchain technologies can enable a decentralized, peer-to-peer **computing platform,**[74] based on **programmable trust and value** that is censorship resistant and corruption proof.

From a more technical perspective, blockchain is a networked data infrastructure with build-in programmable trust, that enables **trustless collaboration** among mutually mistrusting actors by verifying, timestamping, and synchronizing inputted data. A blockchain network can be permissionless or permissioned, while hybrid systems are also possible.

- A **permissionless** blockchain refers to the idea that no permission is needed to join the network of shared data; participation is open for everyone.
- A **permissioned** blockchain refers to a network for which an actor needs permission to participate; it is a closed collaborative environment.
- Appendix 2 provides more details about the differences between permissionless and permissioned blockchains.

Either blockchain type can publish the shared data **publicly** or **privately**. A hybrid combination, in which some data is private while other data is public, is also possible.

Table 1 provides an overview for these four types of blockchain networks. Using an **interoperable hybrid mix** of permissionless and permissioned blockchains, allowing for both public and private data, may be required for complex business use-cases.

Permissionless blockchains	Permissioned blockchains
1.1) Private data	2.1) Private data
1.2) Public data	2.2) Public data

Table 1: Various types of blockchain networks.

[73] Horowitz, B. (2018). Ben Horowitz explains the rise of crypto. Retrieved from youtube.com

[74] Storecoin (n.d.). About the Storecoin p2p cloud computing platform. Retrieved from storecoin.com

In this paper, however, *blockchain is defined as an **open and networked data structure**, in which participants are **free to join or leave*** (type 1.2). Data stored on these blockchains is **immutable** due to cryptographic protocols that disallow data entry history to be reversed. Permissioned blockchains are excluded in this definition, as the more generic term "**Distributed Ledger Technology**" (DLT) can be used to describe the types of synchronized data networks that requires permission to participate.

Taking the view that blockchains are a new data infrastructure for networked and timestamped data, it can be argued that this system consists of four main elements, as explained below. Figure 1 presents these four elements in a graphic.

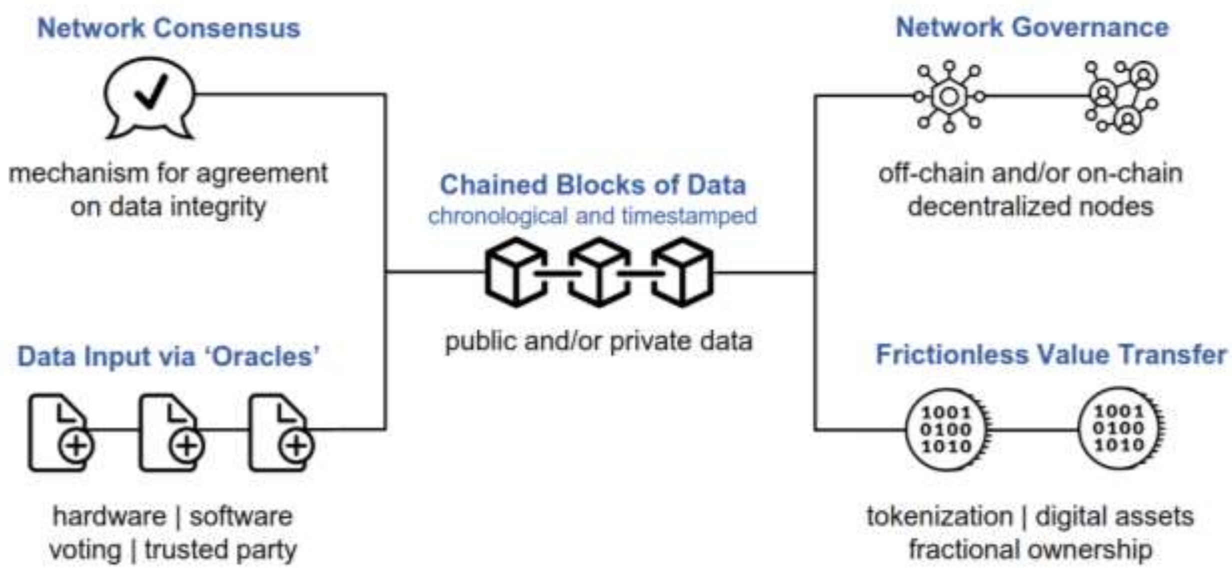

Figure 1: An overview of the central elements in a blockchain-based data network.

1. **Data input** via so-called 'oracles'. Oracles can be hardware-based via sensors or software-based via a data stream. Data can also be inputted on a blockchain through voting consensus or by a trusted party, such as a certification organization or a notary. Most on-chain data in existing blockchains are text-based records of bundled transactions due to current scalability limitations of these systems. It is expected that other non-text-based types of data, such as images or videos, can be stored and shared via blockchains on decentralized cloud storage in the future.

Since data becomes immutable when it enters a blockchain, it is essential to have correct data flowing into the system - garbage in equals garbage out.

2. A **consensus mechanism** to verify and synchronize newly inputted data in the network. A consensus mechanism sets certain rules and parameters that enable the participants in the network to come to an agreement of the validity and integrity of the data. These rules also determine which participant(s) can package the data to the next block and timestamp it prior to adding it on the blockchain. There are dozens of different consensus mechanisms and multiple algorithms per approach. Proof of Work, which requires energy consuming computing equipment to solve random math problems, and Proof of Stake, which is based on staking tokens and therefore requires minimum computing power and energy, are the two most popular approaches. Appendix 1 explains the Proof of Work mechanism in more depth, while Appendix 3 provides an overview of different consensus mechanisms.

3. A **governance model** to distribute power, decision-making, and responsibilities in the network. Governance is arguably the most important element of blockchain technology, as it determines how the rules, stakeholder types, and incentives in the network are established and changed. It also determines the decision-making processes for these changes. Governance models can be executed via 'off-chain' mechanisms like voting by network participants, or via 'on-chain' methods by programming governance rules in the blockchain software that is run by the collaborating actors. A hybrid combination, by which some rules are hard-coded and other decisions are made off-chain, is also possible to govern the network. A high degree of decentralized governance is arguably desirable in open blockchain networks, so that decisions are made in a distributed and democratic manner. Appendix 4 presents an overview of various governance models.

4. **Frictionless value transfer**, providing economic incentives for participating in the network. Tokenization and the creation of digital assets enables an actor that provides merit to the network to be rewarded. The merit can take various forms, including sharing data, verifying and securing data in the network as a mining or staking node operator, offering resources to the infrastructure of the network such as data storage and computing power, or developing new functionalities by updating the blockchain software. Moreover, global peer-to-peer value transfers can lead to novel business models, improved efficiencies in organizational and societal processes, as well as innovative shared ownership and co-creation structures.

Appendix 2: Interoperability between blockchains

Different blockchains do not necessarily speak the same language, which might still lead to data silos if various (supply chain) networks utilize different blockchains. Interoperability refers to the capability of **exchanging data**, including **digital assets** and **business logic**, from one blockchain to another[75]. Most blockchain networks do not natively have this functionality and require add-ons to achieve this capability.

Interoperability is important because blockchains can have a different focus and are thus suitable for different use-cases. One blockchain might be fast with a limited scope, while another might offer complex logic via smart contracts. Being able to utilize various blockchains in combination with each other allows for **more flexibility**, potentially increasing the efficiency of a collaborative ecosystem.

There is a growing need for frictionless interactions between blockchains, for instance to use programmable contracts and tokenized value over multiple blockchains. This urges for **standardization** and open protocols as a common language and cross-chain functionality. As blockchains can be seen as a fundamental data infrastructure layer for the communication of value and trust, anything built on top of that infrastructure has the need to be interoperable - whether it be transactions, information or logic.

There are numerous projects that work on interoperability capabilities, using various approaches to serve different goals. An incomplete list is provided below.

- Multi-chain architecture[76]: Komodo, Dragonchain, Polkadot, Cosmos, Ardor
- Bridging protocols: Chainlink, Interledger, Hybrix
- Cross-chain tokens and trading: AtomicDEX, NIX Platform, Flarewallet, Pantos
- Side Chains (for Bitcoin): Lightning Network, Liquid

[75] Larsen, A. (2018). A Primer on Blockchain Interoperability. Retrieved from medium.com

[76] A multi-chain architecture refers to the idea that there are many blockchains in one ecosystem which can communicate to each other. Data can be aggregated before being validated on a desirable trust level. A multi-chain architecture ensures scalability as not all nodes need to validate and store all data.

Appendix 3 Decentralization versus centralization

One benefit that is often mentioned in blockchain technology is the concept of decentralization – having no single authority or point of failure for a certain aspect of the system. The way from centralization to decentralization is a spectrum, and not a binary value. A general rule is that more centralization can lead to more scalability, throughput and speed, whereas increased decentralization in a network may result in more security, censorship resistance and protection from manipulation. However, with recent advances in the development of the technology, some teams claim to have solved the **blockchain trilemma**[77], which would make the compromises between centralization and decentralization irrelevant.

However, in some cases a centralized oracle is needed for data input or notary purposes, for instance a third party that verifies farming certifications. For software-based oracles, such as weather data or market price information, multiple sources can be used together to decentralize the data stream. Being aware about which parts of a blockchain network are (de)centralized and for which reasons can be valuable, as decentralizing one part of a system can result in more centralization elsewhere.[78]

[77] The blockchain trilemma refers to the idea that an open blockchain has to compromise in terms of decentralization, scalability and security as it can only achieve two out of three.

[78] Schneider, N. (2018). What to do once you admit that decentralizing everything never seems to work. Retrieved from hackernoon.com

Appendix 4: The Physical Digital disconnect

One of the challenges that need to be addresses in blockchain for agrifood is the physical-digital disconnect. Blockchain is of course a digital tool for tracking and tracing. However, the digital information registered in the blockchain needs to correspond with information in the physical world. For example, if you're storing a quality test in the blockchain, how do you make sure that the tested product in the blockchain is the same product that the customer sees when he's checking the blockchain? Technology is needed to make sure that the psychical product is connected to the shared digital blockchain reality.

A way to connect the physical world to the blockchain is by using microchips or QR-codes, for example, in or on a sealed box, bag or container. By scanning the QR-code you access the product information stored in the blockchain. ScanTrust is a solution with patented QR-codes that can't be reprinted and put on another product. Therefore, a sealed bag with a scannable ScanTrust QR-code contains the same products during all stages of the supply chain.

Simplifying data input and using added technology, also helps with preventing human error when inputting that in the blockchain. Simply scanning a product to verify its arrival in a certain place in the supply chain is less error prone than manually inputting that data.

Appendix 5: Transaction lifecycle

This section provides a more in-depth understanding of how a transaction is generated, validated and packaged into a block onto a blockchain.

Step 1. Proving ownership by cryptographically signing a transaction

When a participant in a blockchain network wants to submit a transaction that transfers a digital asset (data, cryptocurrency, tokenized value), the actor must first confirm ownership of the asset. This cryptographic certificate can be validated by everyone in the network. The digital signing technique behind these certificates is called public/private-key encryption.

The basic concept of this technique, based on the work of Diffie and Hellman[79], is an encryption mechanism with two keys.

- a public key, an username which is shareable with everyone
- a private key, a password that must remain a secret

A message that is encrypted with the secret private key can be decrypted with the public key only and vice versa. Figure 2 provides a visual representation of certifying, or digitally signing, a transaction using these keys - in this figure, 'Hello Bob' represents the transaction data.

By encrypting the message with her private key and adding the encrypted message to the message itself, Alice can show Bob that it was her signing the message. Bob can decrypt the encrypted part with the public key of Alice and compare the outcome with the original message. If these two are the same, it was Alice that signed the message.

[79] Computerphile (2017). Secret Key Exchange (Diffie-Hellman). Retrieved from youtube.com

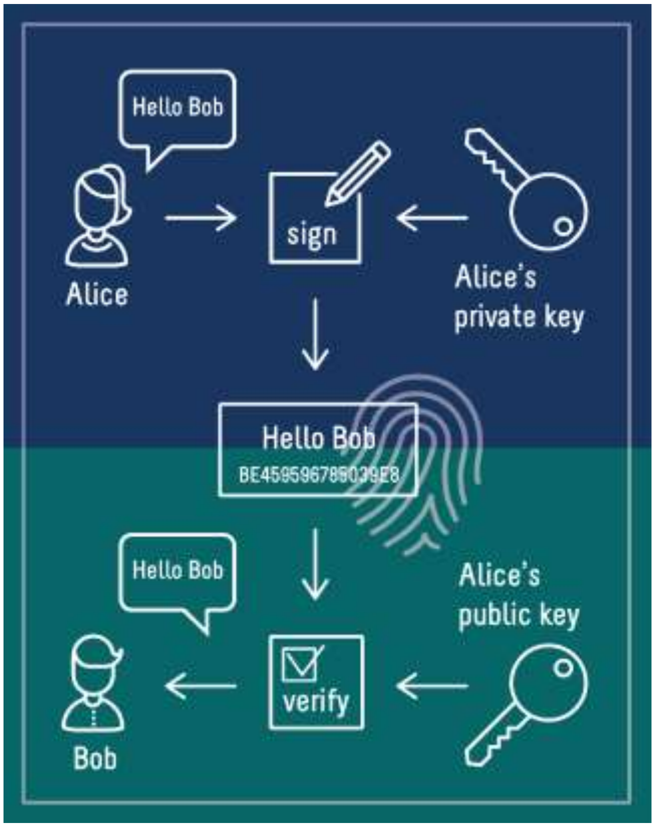

Figure 2: A schematic representation of a cryptographically signed transaction.

Step 2. Aggregating the transaction into a block

When a transaction is created, the validators of the blockchain check it for validity through a process of hash checking. Validators are a type of *node* that all blockchain networks have, yet other types of nodes can exist for different functions. Validator nodes check every transaction against a set of rules, including a check that the assets transferred are really owned by the signer of the transaction to prevent double spending of assets. This can be done without the need for access to the private key that was used by the signer. Transactions that do not comply are rejected. Nodes that have a role of *miner*[80] bundle the validated transactions together in a block. Each miner does that on an individual basis.

[80] Depending on the organization of a blockchain network, miners can have other names like *block producers* or *masternodes.* It is possible that one node has several roles, i.e. both a validator and miner.

This block is chained to the already existing chain of blocks by including a digital fingerprint of the last block into the new block. This digital fingerprint is unique and a change to a single piece of data in the previous block will change this fingerprint. Figure 3 presents a schematic of this process. Since each block contains a fingerprint of the previous block, and all blocks are synchronized with all participants in the network, it is virtually impossible to make changes to the data in a previous block without it been being detected.

Figure 3: A schematic representation of fingerprinted blocks of data.

Step 3. Consensus

The next step in the transaction lifecycle is that the nodes must reach consensus about which block is the next block in the blockchain. The way consensus is reached in the network depends on the type of algorithm or protocol that is implemented in the blockchain. There are many different types of consensus mechanisms.

One approach that is commonly used to reach agreement in a blockchain is the Proof of Work (PoW) consensus mechanism. A generic Proof of Work consensus protocol is explained below.

- The miners in a blockchain network are in a competition to find a solution to a problem that can only be found by random guessing. The fact that these nodes must use brute force to find the solution means that the odds for finding a solution is equal for all participants, based on the computing power that is dedicated to find the solution.
- The input for this problem is the block that has been created in step 2.
- The miner that finds the solution first sends this, together with the newly created block, to all nodes (continued in step 4).

Step 4. Adding the block to the blockchain

Upon reception of a new block, all nodes individually validate the solution found by the winner. The nodes validate the contents of the block and add the new block to their own copy of the blockchain if all checks are valid.

The validation includes checking all the transactions in the block against the same list as used in step 2. This prevents malicious nodes to add self-created transactions that are invalid. If a block is found invalid, it is discarded, and the next winner gets a chance to add a block to the blockchain. After this last step, the blockchain is ready for its next block and a new cycle is started.

Step 5. A reward is given to the block producer

The node that wins the right to add a block to the blockchain is rewarded for the effort, which is typically a digital asset or cryptocurrency specifically made to incentivize participation in the network. The height of this reward determines if people are willing to put effort in operating a blockchain mining node.

The proof-of-work mechanism described above makes fraud near impossible and the transactions in a block trustworthy. The more blocks that are created after the addition of the current block, the more immutable that previous block, and its contents of transactions have become.

This last step completes the transaction life cycle. The transaction is immutably and transparently stored in the blockchain, thereby simultaneously synchronized among all nodes.

Appendix 6: Permissionless and permissioned blockchains

This section provides more detailed information regarding the differences of permissionless (open) and permissioned (closed) blockchain solutions.

Permissionless blockchains

The age of public blockchains (hereafter "blockchains") began in 2008, when a pseudonymous called Satoshi Nakamoto published the whitepaper 'Bitcoin: A Peer-to-Peer Electronic Cash System'.[81] The main innovation proposed in this whitepaper was a novel way to solve the Double Spending Problem[82] of a digital currency on a distributed system with no trusted third party involved. This was a problem that had eluded engineers for decades and in the process Nakamoto showed a way of creating a so-called Byzantine Fault Tolerant (BTF) system[83].

Bitcoin launched in 2009 and eventually developers caught on to the idea that being able to transact directly on a ledger that is capable of storing data might have other use cases. One of these projects is called Ethereum, which was announced in 2014 and launched in 2015. Ethereum enabled developers to write and store code on their blockchain, enabling the development of so-called 'Smart Contracts', potentially vastly increasing the scope of possibilities of what blockchains can do. Since then, the Smart Contract market has been expanding greatly and almost all new blockchain networks have this capability in some way.

Smart Contracts, or automated contracts, are immutably stored procedures with the added value that users can be absolutely sure the contracts cannot be tampered with. This differentiates them from traditional software-based contracts that always poses the risk of being tampered with. The software of these blockchains is commonly maintained and developed by an open-source governance, attracting a community of developers from all over the world.

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[81] Nakamoto, S. (2008). Bitcoin: A Peer-to-Peer Electronic Cash System. Retrieved from HYPERLINK "https://bitcoin.org/bitcoin.pdf"bitcoin.org

[82]"Double-spending is a potential flaw in a digital cash scheme in which the same single digital token can be spent more than once" (.wikipedia.org).

[83] "In a Byzantine fault, a component such as a server can inconsistently appear both failed and functioning to failure-detection systems, presenting different symptoms to different observers. It is difficult for the other components to declare it failed and shut it out of the network, because they need to first reach a consensus regarding which component has failed in the first place" (wikipedia.org).

Pros of permissionless blockchains:

- Blockchains are extremely resistant to censorship and cyberattacks due to the distributed nature of their networks.
- Open innovation and open-source development can lead to quick improvements in the software.
- Data stored blockchains networks can be immutable.

Cons of permissionless blockchains:

- There is not enough regulatory clarity on how to handle blockchains and frictionless value transfer capabilities due to its global nature. Cross-border jurisdiction can lead to challenges.
- The open nature of public blockchains means new ways to ensure privacy and GDPR compliance are needed.
- Open-source governance models might be too immature for key infrastructure.
- There is a lack of competent developers as not all blockchains allow programming in well-known languages, and developers need to learn to code for the use-cases and technical workings of blockchain technology.
- Businesses are generally unfamiliar with the trust model of blockchain technology and have no experience in how to set up processes for them or integrate the data architecture into existing processes.

Permissioned blockchains

Since 2015, some more traditional and incumbent parties that felt uncomfortable with the revolutionary open structure of blockchains, have created versions of blockchain software that are more in line with traditional processes.

The main areas where these initiatives focus on is in limiting or controlling access to users, access to data, as well as the selection of validators and operators of nodes. Two noteworthy permissioned DLT projects are IBM's Hyperledger Fabric and R3's Corda.[84] Both aim directly for enterprise application and are more directly compliant with existing regulations for enterprise grade software. DLTs can are also be created on an ad-hoc basis by several companies, for instance using the Monax or Multichain software.

[84] Sandner, P. (2017). Comparison of Ethereum, Hyperledger Fabric and Corda. Retrieved from medium.com

Pros of permissioned blockchains:

- Because private DLTs are not or less distributed, the system can be scaled using known methods.
- The regulatory landscape is much better known.
- Less vulnerable to attacks known for existing processes.
- Easier to design processes for, because the development model is similar to existing software.

Cons of permissioned blockchains:

- Private DLTs do not benefit from some of the features of public blockchains, like censorship resistance and data immutability.
- Private DLTs cannot benefit from advances in public blockchain technology because they are rooted in the old paradigm.
- Private DLTs offer no substantial upside when compared to existing shared database technology.

Private DLTs can be an interesting way to "test the waters" if you are unfamiliar with blockchain technology. As a technology, however, it is arguably a dead end due to certain open-source blockchain software offering similar features with a bridge to public networks. As such, private DLTs have barely any use-case outside its own walled garden.

Appendix 7: Consensus mechanisms

This section presents a graphic about various consensus mechanisms used in blockchain networks. Proof of Work and Proof of Stake, of variants thereof, are the most popular algorithms.

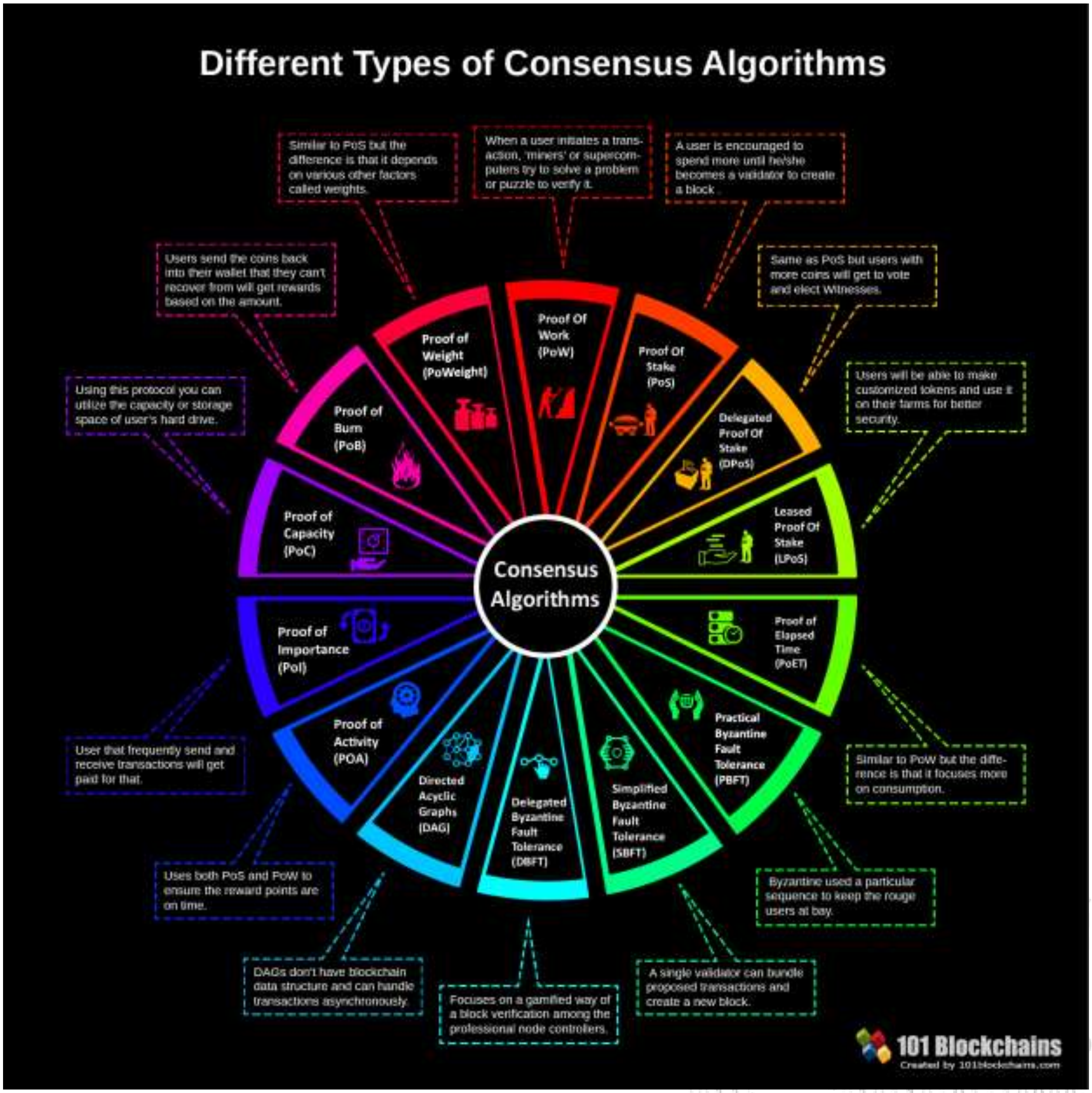

Figure 4: Various types of blockchain consensus algorithms[85]. Click the image for higher resolution.

[85] 101blockchains (2018). Consensus Algorithms: The Root of The Blockchain Technology. Retrieved from 101blockchains.com

Appendix 8: Governance models

This section presents two frameworks to think about various blockchain governance models.

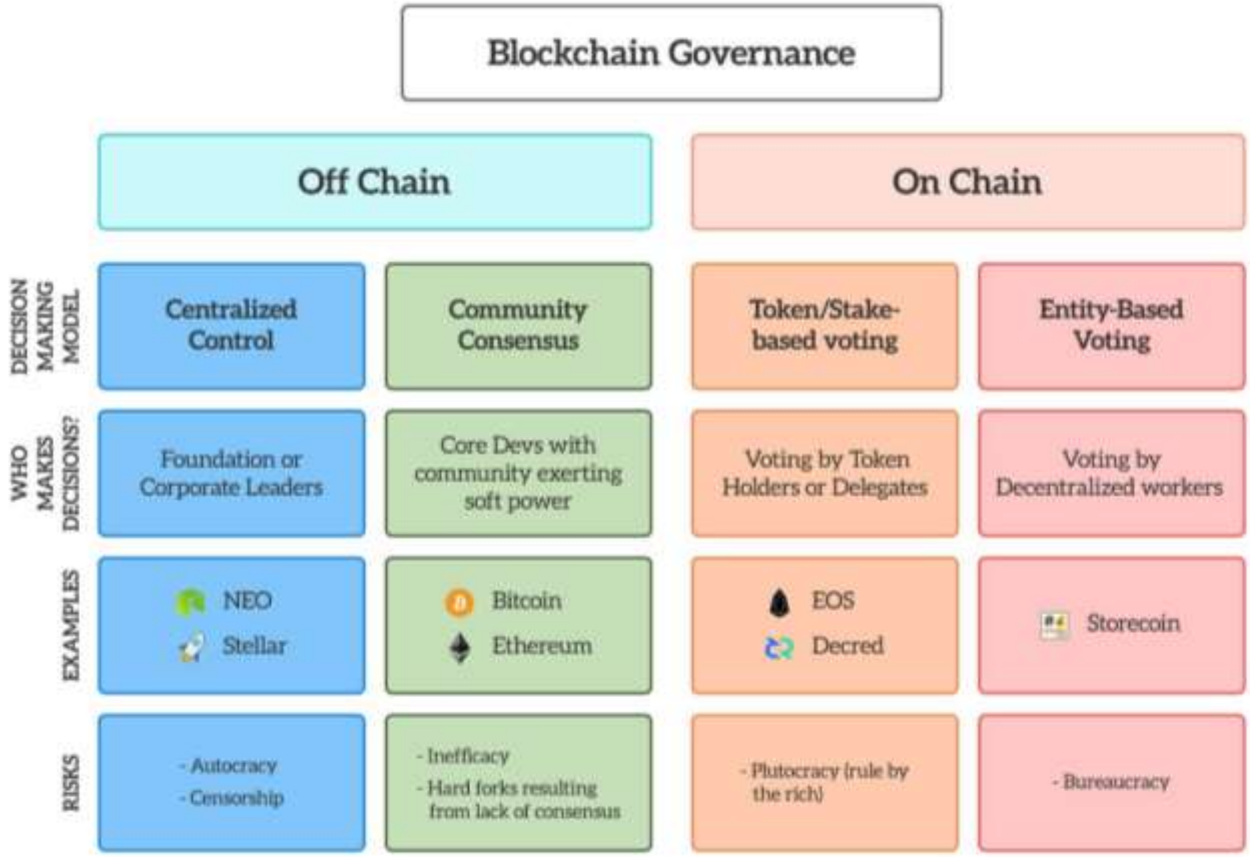

Figure 5: A mental model in terms Off Chain and On Chain governance models[86]. Click the image for higher resolution.

[86] Storecoin Research. (2018). An Overview of Storecoin's Governance. Retrieved from storecoin.com

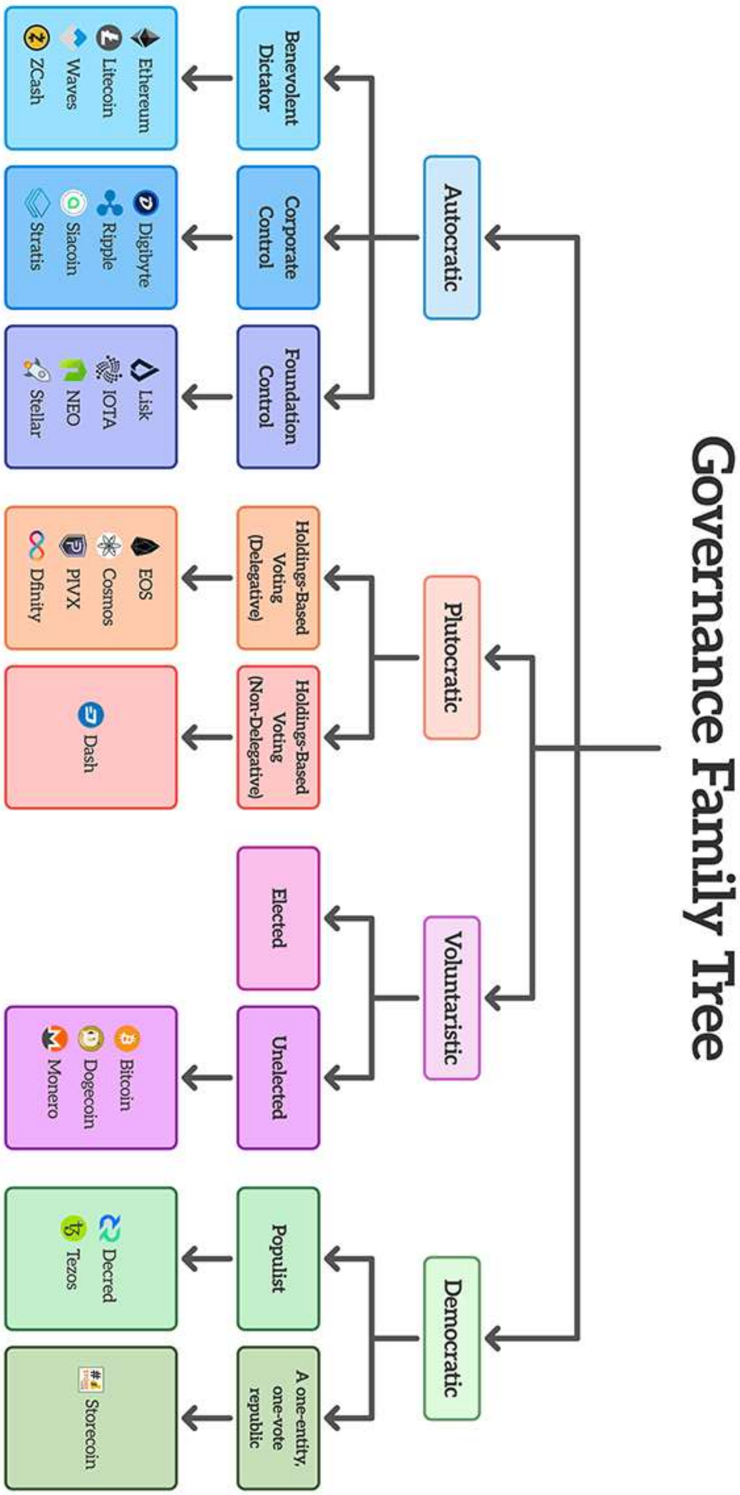

Figure 6. Various governance family trees visualized.[87] Click the image for higher resolution.

[87] Storecoin Research (2018). Blockchain Governance, Trade Offs, and the Importance of a Checks-and-Balances based Decentralized Governance. Retrieved from storecoin.com