DIGITAL TRANSFORMATION WITH BLOCKCHAIN

New Frameworks for EO Information Services

Issue Brief

March 2020

The European Space Agency's (ESA) role is to catalyse European innovation within the Earth Observation sector by introducing new ideas, featuring new methods and systems and enabling bold and innovative solutions. In 2019 ESA has released a White Paper on "Blockchain and Earth Observation" to define the key focus areas for the EO community to explore in the context of the Space 4.0 and future digital engineering for space missions. This publication is an "Issue Brief" by the ESA Blockchain / Distributed Ledgers and EO Community of Practice (CoP) and providing in-depth analysis of one of the priority actions identified by the White Paper for implementation as a part of the DLT technology research, development and proofing. The version of this article has been published by the "Blockchain: Law and Governance" Springer Book, 2020.

How to cite this report: Anna Burzykowska, Digital Transformation with Blockchain, New Frameworks for EO Information Services, March 2020

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INTRODUCTION

The 2018 ESA White Paper on "Blockchain and Earth Observation" refers to the blockchain technology (and other forms of distributed ledgers) as a revolutionary tool for the future growth of the global digital economy[1]. Blockchain's main potential lays in replacing monolithic and centralised data management structures by a distributed system, in which people and organisations can participate in trustworthy, secure, transparent networks that enable a direct collaboration (peer-to-peer). It offers the vision of a data ecosystem where information and digital value exchange can be conducted in a verifiable and privacy-preserving way, and with full and automatic traceability of all transactions (data processing and value chains).

The blockchain industry is currently at the center of the European agenda for the so-called "Deep Tech" industries which span all key cutting-edge disciplines such as Artificial Intelligence (AI), quantum computing, computer vision, robotics, nanotech, and, indeed, blockchain. As a result, the conceptual applications of distributed ledgers, their business potential, and implementation feasibility have grasped the interest of governments, investors as well as the rapidly accelerating community of developers and users of distributed applications (DApps). The report released by McKinsey in 2019 has nevertheless stated that while many prototypes have been built between 2017 and 2019, "the blockchain applications have not yet seen the application at scale".[2] This is why blockchain is often referred to as an emerging technology, one that, much as AI, will develop to the full maturity in the next five to ten years (possibly faster). Nevertheless, even today, at this early stage of adoption, there are important characteristics of the blockchain-based data architectures that call for a deeper insight into the driving forces which enable these first pilot applications, and the foresight into the future use case scenarios that will be revealed in the 2020 decade, once the technology proves added value and becomes mainstream.

This paper focuses on the two application areas where the blockchain technology (distributed ledgers) intersects with the Earth Observation (EO) technology: blockchain-based land registries and data value chains for natural resources management. They both have made important progress in the past two-to-three years and made a direct impact on our understanding of how the digital representation of physical assets and transactions can transform the economic environment around the land administration and management. In this context Earth Observation technology provides the network of sensors that can connect the physical environment to various (centralized and decentralized) digital data repositories. This concept is known as a Digital Twin though which it is possible to apply EO-based imagery to derive information corresponding to the physical representation of natural and man-made objects. Blockchain, on the other hand, is a technology through which a record of this data (and the processing chain) can be conveyed and shared across the product value chain. One of the blockchain objectives is therefore to provide transparency and traceability of the data flow: EO data, logistics data, socio-economic data, financial data, trade data, etc. In other words, the emerging distributed end-to-end platforms certify where the data is coming from, who collected it, how it was processed, what happened to it as it went through the value chain, and provide accountability of all of the transactions and processing steps. In data science it is referred to as a Verifiable Claims Data Model through which the data shared across the parties to the distributed network is linked, cryptographically secure, privacy respecting, and machine-verifiable[3].

Such machine-readable information, is further considered a foundation for a new data retrieval and processing model, called federated learning (or decentralized AI), which is based on the availability of a massive, multisource and real-time data through a range of sensors currently being deployed (i.e. satellite sensors, Internet of Things sensors), which coupled with blockchain and Artificial Intelligence analytics is expected to underpin the next generation of information services[4].

This paper focuses on the few selected case studies that show the potential for the convergence of EO and blockchain platforms to demonstrate the cutting-edge thinking about how EO technology can be used to advance development of blockchain applications, how blockchain can be incorporated into EO product and service design, and what sorts of new tools and methods can be built on blockchain and EO cross over. These case studies are related to land tenure, agriculture and forestry value chains where several important proofs-of-concept have been developed to shed more light concerning the feasibility and lessons learnt from the first implementations.

EARTH OBSERVATION AND THE CADASTRAL INTELLIGENCE

It may not be immediately evident to an average consumer of weather news or public services such as water or air quality, or flood early warning, however our lives are powerfully supported by the stream of information provided via the European public satellite infrastructure. Europe today is at the forefront of the information revolution enabled by the Copernicus Programme conceived through a collaboration between the European Union and the European Space Agency. The Copernicus is, and will remain for decades to come, the biggest system providing globally the key data about the state of our planet and supporting various policies from land management, to forest management, to marine or civil protection and agriculture, revealing information about, for example, physical extent of forests, agricultural fields and land plots, type of harvest, yield, productivity, water use, precipitation, etc.

The Copernicus data are routinely coupled with an increasing number of commercial imaging systems (aerial/satellite/drone platforms) that are capable to map every square kilometer of the planet with a resolution ranging from meters to few tens of centimeters, and enabling location-based services as well as a range of mapping products based on precise cartographic measurements. As a result of these new imaging technologies it is possible to leapfrog the long standing obstacles related to identifying, surveying and mapping the boundaries of land parcels. The technology is sufficiently advanced to enable a rapid word-wide adoption of digital cadaster – an important challenge given that only 30% of global populations have today secure and accurate systems available to them for the adjudication of ownership or use of land rights. The remaining two thirds of global populations, mainly in developing countries, sustain legal void as well as data gap concerning their land and property rights.

Poor land administration and lack of formalization of the land ownership is a well-known challenge to international development and often results from policy, regulatory, governance and cultural barriers. They are often driven by the complexity of traditional (often) shared land ownership structures which are difficult to formalize in a statutory tenure. Nevertheless, there is a consensus that having access to up-to-date geographic information about the land is a key prerequisite for the establishment of the national land tenure system, including the cadaster and certification of land titles.

A typical basis for the cadastral surveys is based on photogrammetry – aerial (or satellite) imagery acquisition and processing followed-up by ground surveys to geocode and check the actual location of legal boundaries of land parcels. The resulting cadastre is a parcel-based system which contains geographically-referenced information and unique, well-defined units of land. These units are defined by formal boundaries marking the extent of land. Each parcel is given a unique parcel-number[5].

Today, many rural communities are carrying out the titling and digitization of land parcel information in a participatory, or community-driven process. In countries where digitization does take place, land owners are given an option to collectively support official surveyors to identify the location and size of their specific land plots reflecting the community's customary rights. In such cases, cadastral survey, especially for agricultural parcels, is conducted using remote sensing imagery (i.e. VHR (Very High Resolution) imagery) as a base on which it is possible to outline the parcels: manually on-screen or by walking the field boundaries with a handheld GPS (Global Positioning System)[6]. Increasingly the rural communities take advantage of the availability of smartphones where satellite imagery serves as a background image for on-screen digitization of parcel boundary acquired directly from the smartphone phone (or a tablet) equipped with the GPS. Such participatory processes which is collecting field boundary information in the field and on the spot is making digitization of individual parcels more inclusive, cheaper and more efficient.

One example of such land mapping and adjudication is a project implemented by the European Space Agency (ESA) with IFAD (International Fund for Agricultural Development, an UN Agency) to demonstrate the feasibility of imaging technologies for land parcel identification and to assist the government of Madagascar in providing small farmers with land ownership certificates based on the use of VHR satellite imagery. This offered the rural farmers the first opportunity to formalize their land ownership. To simplify the designation and exchange of land titles, a detailed image database was provided to enable the classification and delineation of land concessions and properties. Maps were produced for three districts in Haute Matsiatra which good approximation of the location and size of specific land plots (see Figure 1). In other countries, such as Kenya and Tanzania, it is sufficient to manually record the dimensions of any land parcel through a digital imagery map, so long as its boundaries are clearly visible on the photographs[7]. The future imaging techniques, currently tested, will expand this manual parcel delineation to involve the machine deep learning allowing automated detection of the land parcels using VHR imagery, and automated object recognition[8].

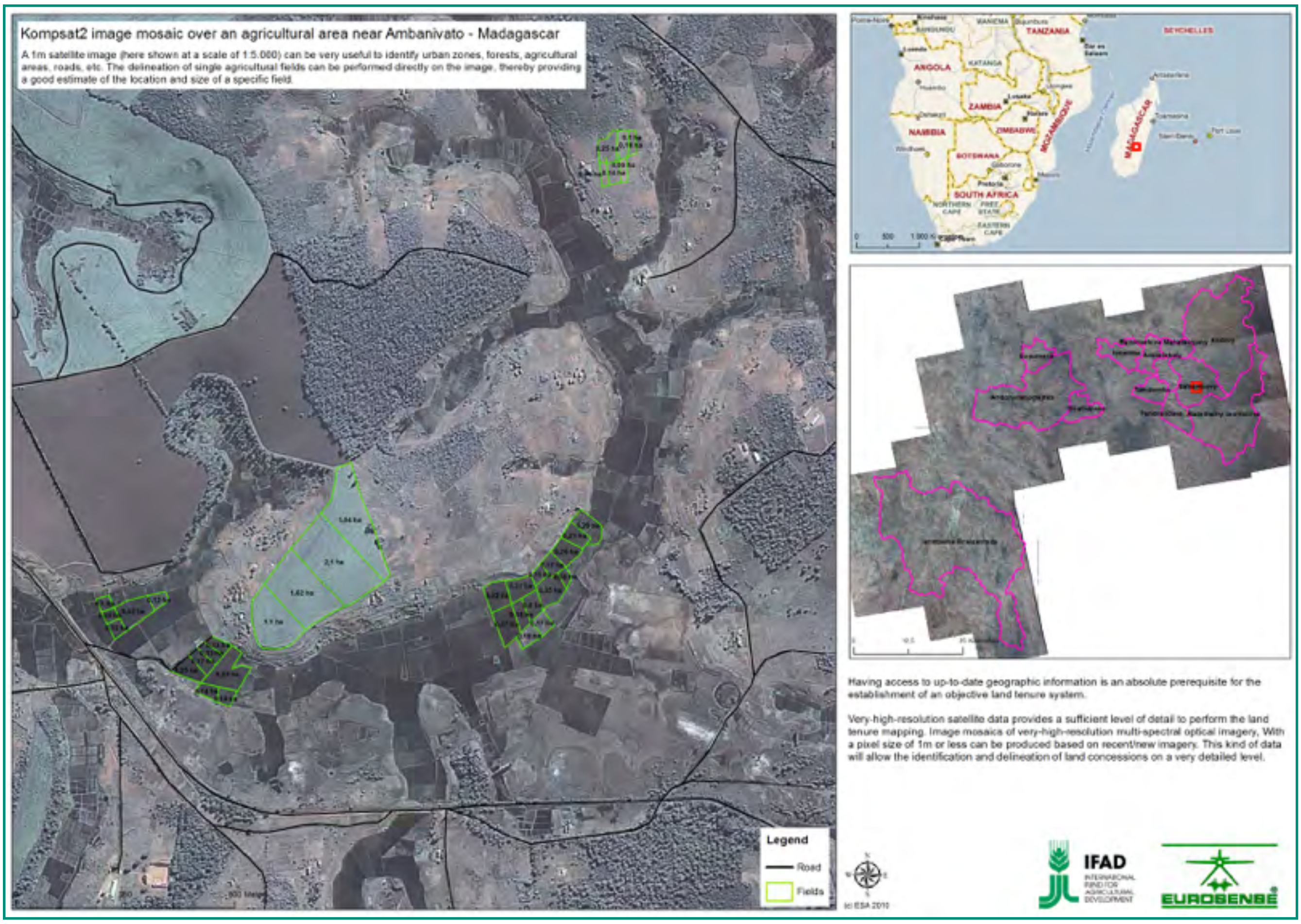

Figure 1 Field delineation of three districts in Haute Matsiatra based on 1 m-resolution satellite data to support ongoing land reform in Madagascar (Plan Local d'Occupation Foncière). Credit: Eurosense for ESA/IFAD

BLOCKCHAIN REVOLUTION

Blockchain technology is considered to be another breakthrough in creating modern land registers. The countries such as Sweden, Georgia, Ukraine and Rwanda as well as Ghana, Zimbabwe and Kenya are currently launching initiatives to test the use this technology as the basis for their land registers and to incentivize collection of land ownership information, with Sweden leading the pack[9].

The key reason to adopt blockchain-based database as a basis for the national land registries is rooted in the fact that blockchain technology offers a means to enhance the transparency, security, accessibility and efficiency of land register and associated land transactions. In theory, a blockchain-based permanent, public "ledger" (a database) can contain all land records including details of the tenure and/or transfer of ownership, and as such can be accessed digitally by multiple parties (individual owners, public administration, banks, insurance companies, asset brokers, etc.), shared without restrictions among them and updated in real time. Such ledger due to the immutable character of the blockchain data structures, cannot be falsified or tampered with. Once deployed operationally the public and shared character of the ledger can also – in theory - eliminate the need for an extensive bureaucracy to manage and validate (or certify) the records, for example, via notary services. The "smart contract" functionality is believed to improve not only the speed of operations for clearing of settlements, but also to simplify the legal process associated with various certifications and third-party verifications (i.e. via title companies, escrow companies, inspectors, appraisers, and notaries). As a result, according to the experts, land transactions can be effected in days rather than months, with a significant reduction in transaction fees[10].

Many commentators agree that such decentralized data structure is primarily aimed to connect different sectors of the economy in completely innovative ways. In Sweden, for example, the proposed blockchain land tenure model entails creation of a shared database in which information about the land property is digitized, put into the distribute ledger and made available for reference in order to facilitate transactions related to a particular property. The banks, buyers, sellers and the national land registry agency (Lantmateriet) can have access to this database and can substantiate/verify the veracity of any given transfer of ownership, agreement (and other documents) through their unique digital signature (hash on the blockchain). The premise is that they would operate on consensus, therefore if any new record, like a property transaction, is added to the blockchain, it has to be confirmed by the nodes operating within the network[11]. In this sense, for example, the banks participating to the transactions can also ensure that the buyer has enough funds in their account before authorizing the purchase of the assets[12]. This unlocks a new potential in credit availability and is considered a fundamental shift in sharing data across industries, as well as auditable value exchange.

Today, Sweden is the most advanced in terms of the application of the technology in land management, followed by Georgia. In Sweden, a blockchain developer - ChromaWay has partnered in 2016 with a consultancy group Kairos Future and the Landmateriet – national cadastral agency to test the applications for property transactions and land titles. The application of the technology via a prototype platform demonstrated the increase of transparency and speed of transactions, and has shown the overall feasibility, however the known hurdles include the legality of digital signatures. Consequently, as of 2019 the application is still in the proof-of-concept stage[13]. Another blokchain company called Bitfury has provided to the Georgian National Agency for Public Registry the Land Register solution based on its Exonum platform which achieved an operational use of blockchain-based databases for land title registration with close to hundred thousand transactions already completed. As Georgian land tenure system is akin to private, permissioned ledger, therefore it was easier to deploy, operationally nevertheless it does not yet fully replaced the legacy of centralised systems[14].

Interestingly, both examples feature (or plan for) the smart contract functionality in their respective land registers, in order to execute, amongst other things, escrow services[15]. This raises important legal questions related to the binding force and enforceability of smart legal contracts (or the so called computational contracts)[16] and the need for their legal and regulatory clarity. From the perspective of the users, they are expected to be agnostic concerning the blockchain (or other technology) back-end that powers the system. The interaction with the applications would not require any special skills other than being comfortable with digital transactions. An example of the application for land titling based on the Exonum platform is presented in Figure 2.

Figure 2 Test-Drive Blockchain-Based Land Titling on Bitfury's Exonum Platform available at https://medium.com/meetbitfury/test-drive-blockchain-based-land-titling-on-bitfurys-exonum-platform-78698fd83b6a

A thorough understanding of the legal matters and governance models related to the application of blockchain technology to land titling and registry is currently at the core of the discussions on further roll out of these solutions to other countries. One thing is evident: for the most part, the application of blockchain based land register is deemed feasible at scale in the countries where cadaster has been fully established and digitized, and where the records of property transactions, which include information on the ownership and title of a specific land plot, exist. However, the majority of developing countries do not have their land tenure digitized (in a form of cadastral maps and land registers) or the ownership rights properly established (beyond, for example, traditional or informal land tenure) and enforced by attribution of formal and unique land titles. If, therefore, the delineation of land plots and digitization of cadaster (including regular updating of cadastral records) and digitization of land registers can go hand in hand, the opportunities for improvements of the national land governance, and administration via the state-of-the-art land information systems are significant, if not groundbreaking. This is where the convergence of Earth Observation (geospatial information) and blockchain comes into play.

EO AND BLOCKCHAIN CROSSOVER

Cadastral surveying, as mentioned before, based on remote sensing measurements can create digital representation of boundaries for the property – or a precise geographical description the borders of the land plot[17]. Once cadaster is established it can take form of traditional centralised land information system, or, thanks to the blockchain data structures, it is possible to create a decentralised platform for land tenure data registration, validation and exchange. Both alternatives serve the same objective - to allow citizens to formalize their land tenure to document their land or property rights in an official and legally binding way through deeds or title certification. In this case, the function of land registers is to provide a proof of authenticity of data, while EO and photogrammetry techniques guarantee that geodetic/geographic information about given land plots are credible and up-to-date.

There are several blockchain companies that are currently developing end-to-end solutions for decentralized land tenure informatics systems which is enabled by the establishment of the cadaster and national land registers. In Rwanda, the national Land Management and Use Authority (RLMUA) and the Rwanda Information Society Authority (RISA) partnered with the blockchain start up Medici Land Governance (MGL) "*to help Rwanda's government incorporate blockchain and other technologies into its existing systems, developing a paperless system that relies on electronic signatures and digital lodging of surveys for the administrative processes that affect land rights and transfers*"[18]. The blockchain solution offered by MLG – Open Index Protocol – is, as of 2019, also developed in Zambia, Liberia, Mexico (and Wyoming, USA). It involves the use of drone-based imagery and other remote sensing technologies as well as a range of GPS tools to capture the location of property assets for extracting parcels, and digitizing existing paper maps on the acquired imagery. Another example is a Ghanaian startup Bitland which proposed the distributed digital ledger to boost the integrity of the land records in Western Africa region. It is currently working in the Ghana's Ashanti Region on a pilot basis and the implementation is supported by land and agriculture surveys via remote sensing (formal account of the results from the pilot phase have not been yet published)[19]. Early applicability of blockchain for land governance supported by international donors, such as the World Bank and the UNDP (United Nations Development Programme), was also tested in Honduras and India[20]. Moreover, in November 2019 Inter-American Development Bank (IDB) announced it has contracted Sweden's ChromaWay to develop a proof-of-concept land titling and registry platform in three South American countries: Bolivia, Peru and Uruguay[21].

The availability of secure and functioning land tenure regulations and databases is considered to be a stepping stone for sustainable development. It has been officially recognized as one of the Sustainable Development Goals, SDG Indicator 1.4.2 which calls for the increase of the "*proportion of total adult population with secure tenure rights to land, with legally recognized documentation and who perceive their rights to land as secure, by sex and by type of tenure*". More importantly, the evidence shows that the availability of a secure land tenure influences the extent to which farmers are prepared to invest in improvements in agriculture production and sustainable land management. This is because land owners are often agriculture producers who are interested in optimizing their farm operations: from boosting production to reaching the markets in a more efficient way. For them the spin off from well-functioning decentralised digital land registers means not only reducing the risk of land expropriation, but also possibility of unlocking the access to finance, and opening opportunities offered by the digital data-driven economy.

Today, thanks to the Copernicus satellite EO system, there is a suite of matured and certified satellite-based operational services available to the farmers to enable data-driven farm production management, or to improve agriculture productivity and market access[22]. These EO-based information services can provide regular information about biomass production levels per plot, farm or agricultural holding, performance of crops (yield prognosis), early warning, assessment of water productivity (i.e. assessment of the amount of water used for the production of agricultural produce "crop per drop", performance of irrigation schemes, compliance with allocated water rights permits), optimization of fertilizer use for precision agriculture, monitoring of organic or sustainable farming practices, and so on (for examples see Figure 3 and 4). Nevertheless, despite an unprecedented improvement in data access policies (in particular the full, free and open licensing scheme for Sentinel EO data), there are still many obstacles that hold back the global uptake of such information especially in those parts of the world with a limited access to the internet, or where data infrastructures are not digitised[23]. Overcoming this digital divide will open completely new opportunities for EO services.

THE NEXT GENERATION OF THE AGRICULTURE VALUE CHAINS

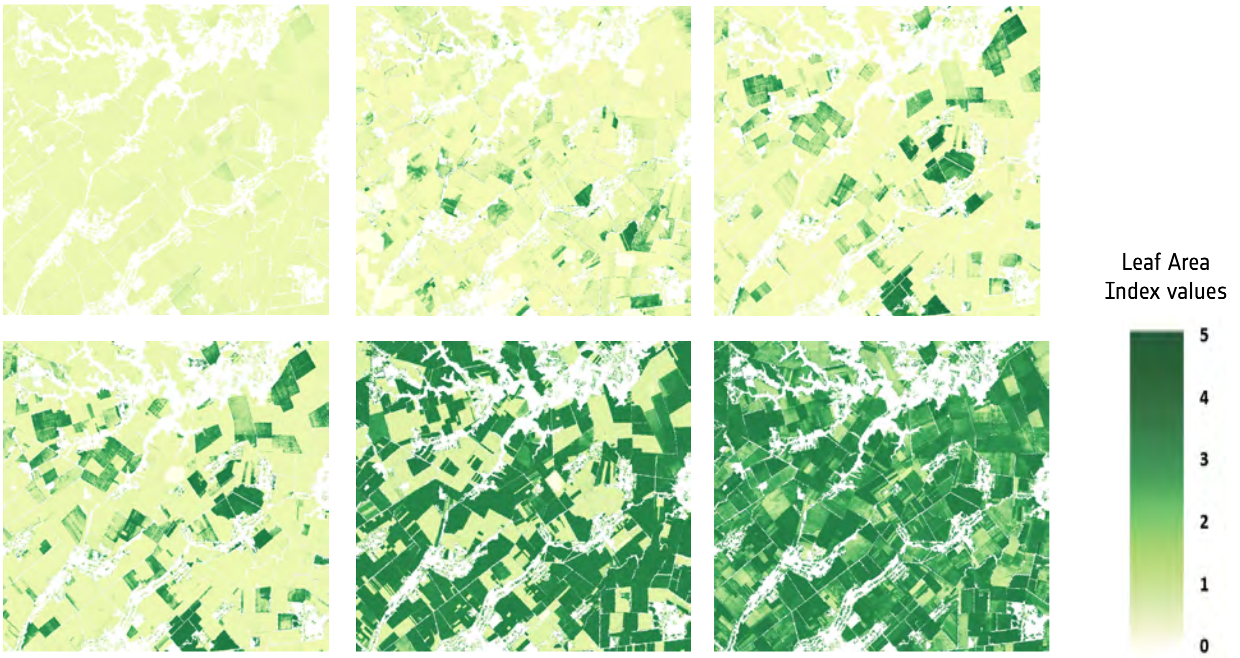

Figure 3 Example of operational crop monitoring throughout the season based on Sentinel 2 data.
Credit: Sentinel2for Agriculture project, national demonstrator in Ukraine.

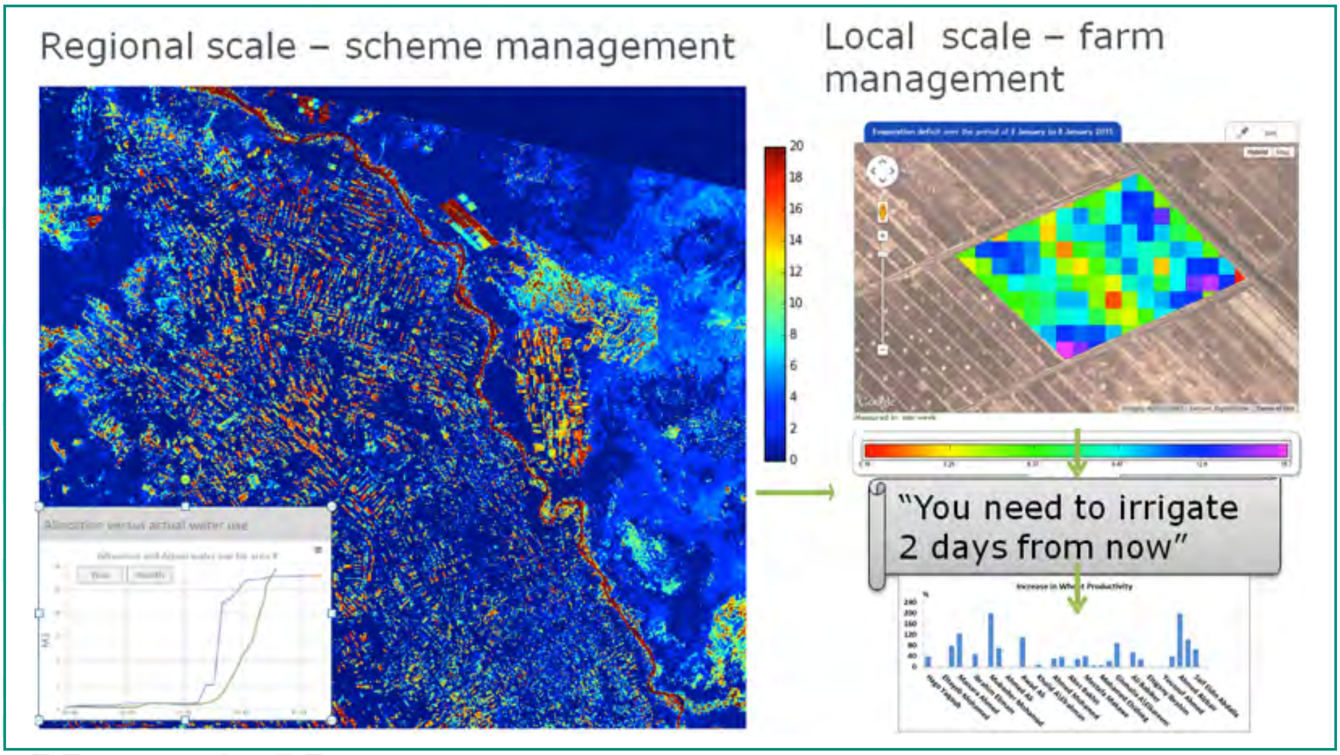

Figure 4 Satellite Earth Observation (EO) technologies provide a low cost methodology to plan irrigation development. It helps in selecting target areas for irrigation development by quantifying water stress and identifying under-performing areas in both rainfed and irrigated agriculture. Credit: Eleaf for EO4SD Agriculture Cluster

The blockchain innovation has certainly revived the interest in digitalisation of processes and businesses across the agriculture sector. It has also revealed the need for timely, accurate, transparent and reliable data records to underpin the value chain and exchange. As a result, several blockchain companies dynamically address the emerging market for agricultural insurance & food and commodities traceability services.

GrainChain, for example, offers a software system that integrates internet-of-things (IoT) data, market data, and farmers data into a blockchain platform for transactions in the agriculture commodity markets. The solution aims to involve banks, insurers, vendors, cooperatives, exporters and farmers to one platform via a smart contract functionality[24]. Its flagship pilot study in Honduras focused on coffee supply chain tracking service and on brokering contracts between the farmers and coffee buyers, along with a digital wallet that enables remote and unbanked farmers to enter, for the first time, a financial exchange system with multiple trading partners.

Trade in Space is another company innovating in this market by the means of fusion of satellite data into smart contracts to enable peer-to-peer commodity trading. The company's TradeWinds platform based on Hyperledger is currently demonstrating services for Brazilian coffee producers and commodity traders using Sentinel 2 imagery for production monitoring.

The long term vision for such developments is meant to unlock new income sources for the farmers, and increase their credit worthiness based on the land management practices and yield prognosis (future income). As a result, the individual farmers can be empowered to enforce the pricing transparency between suppliers and commodities processing (value adding) enterprises and trade their commodity futures.

The future target market for the next generation of these and similar blockchain-based applications lays in the supply system management for agriculture commodities (so called farm-to-fork). For commodities such as corn, wheat, soy, sorghum, coffee, cotton, and livestock there is a range of solutions already being developed and tested by both: innovative start-up companies like GrainChain, Bext360, AgriLedger, AgriDigital, Tradein Space, as well as large corporations such as Starbucks which decided to put the entire supply chain on the blockchain. In line of this trend, the industry giants such as Unilevel and Nestle have committed to the full supply chain transparency via supply chain food provenance on blockchain[25]. The preferred solution is based on the WWF's OpenSC blockchain platform founded by the WWF and the Boston Consulting Group Digital Ventures which is providing monitoring and verification services using combination of satellite imagery, live video monitoring and worker biometric data for sectors ranging from palm oil to fisheries[26].

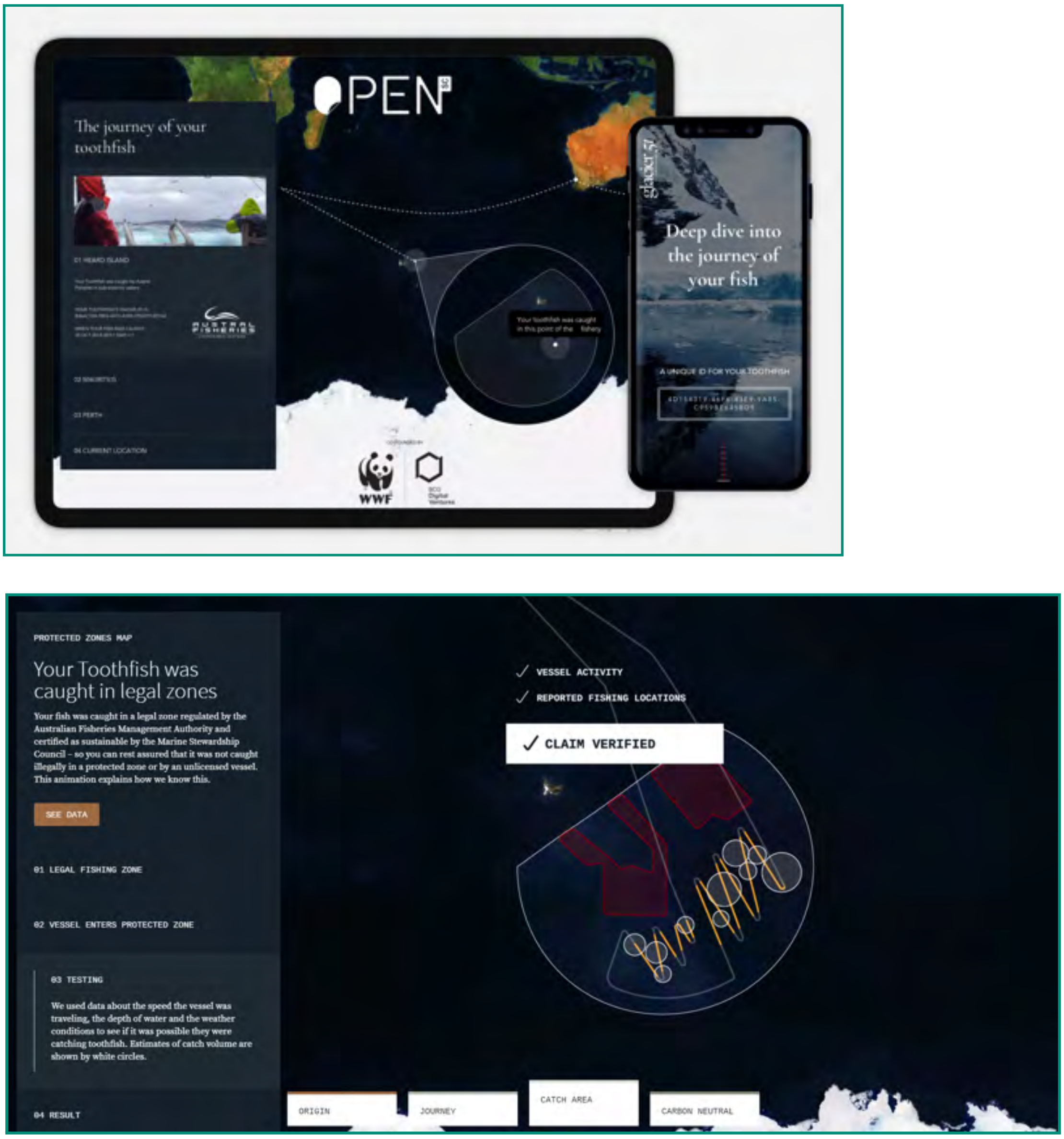

Figure 5 WWF's OpenSC blockchain platform

It is evident that for many forthcoming smart contract-enabled business applications, there is a critical need for trusted datastreams and certified information (highly processed data) to enter the code-executed transaction record, in order to further the operation and/or smart contract execution. Today a large majority of blockchain platform developers rely on IoT sensors deployed in the field for detailed information related for example to yield (actual harvest in kg per ha) or quality of the crop. However, remote sensing techniques (ground, aerial and satellite based) are increasingly used to digitize the production areas (i.e. coffee or palm oil plantations) to provide information concerning the overall grow and state of production.

The recently released report by the UN Food and Agriculture Organisation (FAO) provides an up-to-date overview of other important case studies addressing the use of blockchain and Earth Observation for agriculture including the blockchain-enabled micro-insurance solutions. The FARMS project (Financial and Agricultural Risk Management for Smallholders) stands out as an example of a "virtual platform" integrated with satellite data (EO based drought index) and mobile money solutions to address the agriculture insurance market to deliver transparent secure transactions and information dashboards as well as automated payment of claims via drought coins / vouchers[27].

Another important application area on the crossover of blockchain and EO is related to land administration and monitoring of concession licenses, i.e. verification of compliance with certification requirements and standards in order to screen for production norms and requirements (i.e. land use before a reference date, protected zones delineation to prevent clearance of natural vegetation or primary forest for agriculture activities, monitoring and tracking of the actual crops sown and harvested, etc.). An example of operation EO monitoring practice is presented in Figure 5 which shows a time-series analysis of Sentinel-1 radar and optical Sentinel-2 and Landsat imagery revealing a decade of deforestation caused by the convergence of the forest into agriculture areas within individual land parcels. The application of blockchain technology to these data services can further improve the traceability and efficiency of the wood supply chain by complementing this information with additional data on the industry practices and logistics to enable wood certification or, conversely, deforestation-free commodities supply chain like soy or beef2[8]. These kinds of information platforms can include information about forest inventory, harvesting plans, dates, real-time information sharing of harvesting activities, pulp mill production rates, tracking of processing products, etc.

Finally, such capability is also interesting in the context of the EU Common Agriculture Policy where the national Paying Agencies link farm operations and their compliance to certain farm management practices with the subsidy payouts. Today this reporting is based on the mix of the farmers declarations and on-the-spots checks however in the near future the monitoring will move towards automated data processing based on remote sensing techniques, in situ data and machine learning therefore the full traceability of the data value chain will gain significance given the billions of euros of subventions at stake. Such vision for the EU-led transformation to digital agriculture was highlighted in May 2019 in the EU Declaration of Cooperation on "A smart and sustainable digital future for European agriculture and rural areas" which aims, i.a., to support research, development and innovation actions aimed at achieving improved food traceability through the use of blockchain technologies in agriculture and throughout the food system.

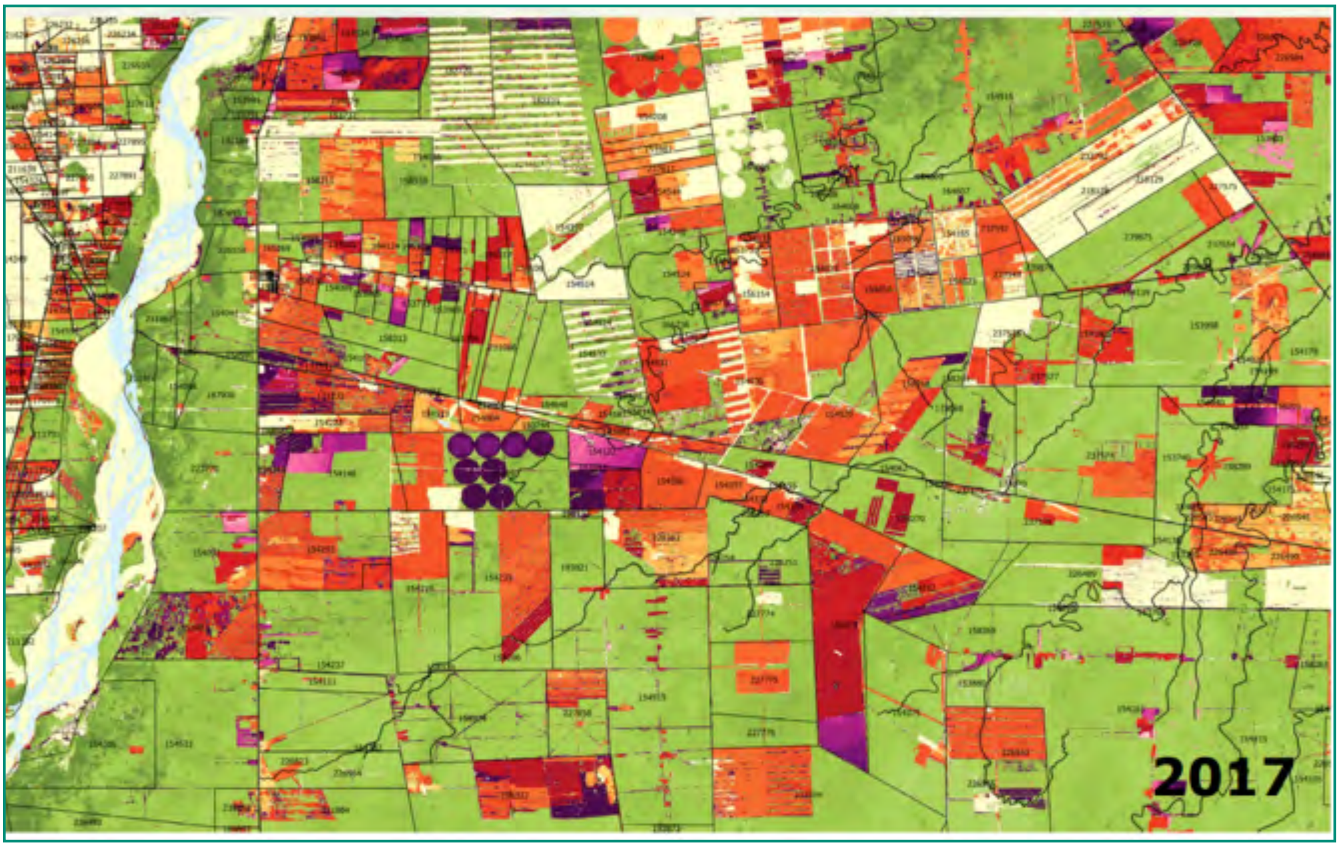

Figure 6 Deforested areas within land parcels derived from time-series analysis of Sentinel-1 radar and optical Sentinel-2 and Landsat imagery. Example from Santa Cruz, Bolivia. Black lines: land title database courtesy of INRA Bolivia. Credit: EO4SD Agriculture Cluster (Satelligence for ESA/IDB, 2017).

NEED FOR FURTHER RESEARCH AND DEVELOPMENT

Earth Observation techniques coupled with the growing blockchain capability can significantly improve the accessibility, transparency, security and traceability of information necessary to implement digital systems integrating resource management, supply chain management and financial, as well as production, economic, or customer information for a variety of market sectors.

While EO services have achieved necessary maturity over the last decade, in the context of the distributed ledgers there is still a need to study deeper the use case scenarios involving adding data content (i.e. spatially referenced and updated land parcel information with associated land use/cover information, land productivity information) to the blockchain-enabled land registers, commodities trading value chains, and other emerging distributed applications (DApps) for forestry, agriculture supply chain or other sectors. The objective is to reveal what kinds of information layers can operate in the framework of blockchain-driven services, what are the critical information needs, for what timescales, at which levels of resolution and content details, etc. As blockchain network cannot be used to store data (it can only carry the land transaction details, not the object of the transaction, such as documents or geodetic information records), therefore it is paramount to clarify what observations (or data points) can be included in the blockchain transaction "block" (i.e. in a form of statistical or predefined metrics such as biophysical values assigned to the given land plot). This will require addressing the need for standardization and certification of EO data product and information services, traceability across the entire EO data value chain to ensure the credibility of EO services and provenance trail of this information, including provenance of original EO data, to the source.

Finally, one most widely quoted challenge for a wide adoption of blockchain platforms is related to the data ecosystem which it is fueled by. If inaccurate data is entered to the platform it will be maintained in the system. This is also why the EO sensor networks can play an important role in this new technology domain by providing objective, accurate and up-to-date data representing the state of the natural environment, or the movement of goods (or a single source of truth validated across different interoperable sensor networks). Other commonly cited technological, legal and regulatory challenges pertain to scalability, interoperability, operational security & cybersecurity, identity verification, and data privacy[29]. Concerning a legal and regulatory framework for the implementations of blockchain solutions the open questions remain concerning the legality of smart contracts, the legal and technical protection measures concerning handling of the sensitive data in this ecosystem, including intellectual property rights as well as data licensing, data rentals and data ownership structures within the blockchain ecosystems.

CONCLUSIONS

There is a large potential of the convergence of different data collection technologies enabled by decentralized data structures (blockchain and other distributed ledgers) which has captured an attention of the developers, governments, investors, users, and legislative and regulatory bodies. The blockchain has been understood to outperform other technologies in terms of data protection and privacy, security, accountability and transparency of transactions involving multiple parties, and a range of implementations have demonstrated the dawn of new era for handling combined information about global value chains. At the same time, the technology poses new types of challenges. These stem from the fact that blockchain may be seen as incompatible with the existing organizational (centralized), legal, regulatory, economic and even societal models.

Overall, the movement to modernize the land tenure systems, including via blockchain innovation, revealed a large number of prerequisites for such transition to decentralized governance, some of them being digital identity, availability of accurate data, digital banking and the ability to deliver information services electronically. Moreover, there are still outstanding questions about the blockchain transactions and how to express legal contracts in the form of computational code (smart contracts). The blockchain ability to track all the data processing related to all transactions has also been deemed a challenge for the existing data privacy and protection laws and will require new legal regimes to be implemented to reap full benefits of this technology. Nevertheless as these questions are set to be clarified by the legal and policy experts in the coming years, it is increasingly evident that a steady trend in which distributed ledgers are embraced by the wider community of public and private users is also primed to transform and augment the way we consume and exchange data in the digital age.

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