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Energy Efficiency in Agriculture through Tokenization of 5G and Edge Applications

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Abstract: This study delves into the potential of 5G and blockchain technologies in smart agriculture, specifically targeting remote farming sectors. A conceptual architecture is proposed, aiming to leverage these cutting-edge technologies while ensuring energy efficiency and sustainable development within the agriculture industry. We provide an in-depth analysis of 5G applications and explore alternative communication channels that could empower remote communities, introducing them to state-of-the-art technological solutions. A unique aspect of our research is the detailed presentation of a parametric insurance business case, designed to align with the proposed architecture, thereby illustrating the practicality of our approach. Moreover, we propose an innovative solution to the challenge of providing internet connectivity in rural areas using Unmanned Aerial Vehicles (UAVs). Current limitations due to the weight of onboard equipment, which includes an access network and a backhaul link for internet provision, are addressed by introducing a lightweight 5G system onboard the UAV. This system serves multiple user equipment on the ground, with one acting as a connection gateway to the internet. This unique approach not only streamlines the process of providing rural internet connectivity but also opens up new markets for service providers and businesses related to lightweight 5G systems and UAV technology. Our work presents an avant-garde solution to technical challenges and offers significant business opportunities in the rapidly evolving telecommunications sector and beyond.

Keywords: 5G; edge; agriculture; blockchain; energy efficiency

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1. Introduction

The ever-evolving application of cellular telecommunication networks, notably 5G, in various fields in recent years has widened the scope and integration capabilities of the telco domain in general. Parallel to the telecommunication network proliferation, blockchain technologies have also emerged in different applications and are continuously adapting to find more target fields to reinvigorate. Decentralization and two-fold data/service disaggregation is a common aspect in both fields and has found multiple converged applications, in IoT, Fog computing, Smart Grid [1–4]. This cross-domain convergence can prove vital and supporting to various under-developed fields and communities, such as the rural agriculture one. Due to low population density and challenging terrain, rural areas tend to suffer from poor or even non-existent digital services, both fixed and mobile: on copper, digital signals attenuate rapidly over distance, while macro-cells that are typically deployed by mobile operators to provide coverage to large areas necessarily sacrifice speed to coverage [5]. Overall cost for service providers is also highly impacted by radio spectrum license fees, further diluting the rural investment case [6]. 5G networks aim to dramatically improve the end users' connectivity capabilities, thanks to a significant increase in the

offered data rates, coupled also with extremely low latency times. Additionally, blockchain-based technologies have already started to penetrate the smart agriculture ecosystem [7] and showcase various applications in the field.

This paper will analyze the advantages of 5G [8] and blockchain convergence for the rural communities, by proposing a holistic 5G architecture with a blockchain based tokenization perspective explicitly designed to include rural areas. The proposed tokenization mechanism is also proposed as an energy efficient alternative to traditional Proof-of-Work (PoW) blockchain methods and can vitally boost energy saving in the rural economy. PoW, the consensus algorithm used in many blockchains, including Bitcoin, requires substantial computational power to solve complex mathematical problems. This process, known as mining, is energy-intensive and has been criticized for its environmental impact. In contrast, the tokenization mechanism doesn't require such energy-consuming mining processes. Instead, it can utilize consensus mechanisms like Proof of Stake (PoS) or Delegated Proof of Stake (DPoS), which require significantly less computational power and, consequently, less energy. Furthermore, the tokenization mechanism can boost the rural economy by providing a more inclusive and accessible financial system. Unlike PoW systems, which tend to favor those with more computational power, tokenization allows anyone to participate in the network and earn rewards, regardless of their computational power. This inclusivity can stimulate economic activity and growth in rural areas by enabling more people to participate in the digital economy. Moreover, the tokenization mechanism can improve the scalability of blockchain applications in rural areas. PoW-based blockchains often struggle with scalability issues due to the fixed time it takes to add a new block to the blockchain. Tokenization can address this issue by enabling faster transaction times and lower fees, making blockchain applications more practical and accessible for rural communities.

Indeed, while the concept of tokenization may seem novel in the context of smart agriculture, it has been previously explored in a variety of applications. For instance, Ref. [9] demonstrated the use of blockchain tokenization in managing the quality of wild-simulated. In another context, Ref. [9] presented how smart contracts and blockchain tokens can be used for third-party certification in the agri-food supply chain. Furthermore, trustworthy wireless sensor networks for monitoring environmental conditions have been introduced, suggesting possible intersections with tokenization for reliable and secure data handling [10]. More specifically related to agriculture, Ref. [11] proposed the implementation of blockchain technology in irrigation systems integrated with photovoltaic energy generation systems, hinting at the potential for tokenization within such blockchain-enabled systems. These studies collectively indicate the emergence of tokenization in various sectors, including agriculture, underscoring the relevance and timeliness of our research on its integration within the domain of smart agriculture and remote farming sectors.

To comprehend the significance of the proposed work in the paper, it is essential to explore the broader context of both telecommunication networks and blockchain technologies. Telecommunication networks, especially 5G, have revolutionized the way we exchange information, with their low latency and high data transfer speeds enhancing a multitude of fields [12]. The advent of 5G has not only made rapid and efficient communication possible but also led to its integration into various sectors, thereby making real-time data transfer a reality. Blockchain technologies, on the other hand, have transformed how we store and verify data [13,14]. With their decentralized nature and high-security framework, blockchains have found use in diverse areas, such as finance, supply chain management, and the Internet of Things (IoT). The convergence of these two technologies is emerging as a potent tool in tackling some of the most pressing challenges in underdeveloped and underserved communities, such as those in rural agricultural regions. The issues these areas face, like lack of digital services, high cost of operation for service providers, and limited access to financial systems, highlight the urgent need for a holistic solution. The promise of 5G and blockchain convergence for rural communities lies in the potential

for improved connectivity, cost-effectiveness, energy efficiency, and financial inclusivity, thereby bridging the digital divide [15]. This broader perspective provides a context to understand the importance and potential impact of the study in the paper.

In summary, the proposed tokenization mechanism can provide a more energy-efficient, inclusive, and scalable alternative to traditional PoW blockchain methods, offering significant benefits for rural and remote areas. The paper is organized as follows: Section 1 introduces the scope and motivation of the work, Section 2 presents an overview of the technology enablers (communication, edge and blockchain) that can improve and empower the agriculture field, Section 3 presents the overall scope of the proposed architecture and how the different technologies can be combined, Section 4 outlines a set of different applications based on tokenization that can benefit rural communities and last but not least Section 5 concludes the manuscript and draws the future outline of the relevant research.

2. Technology Enablers for Smart & Energy Efficient Rural Agriculture

5G networks aim to dramatically improve the user experience, thanks to a significant increase in the offered data rates, coupled also with extremely low latency times [16]. In this way, services like very high-definition video, tactile Internet, virtual reality and Internet of Things will be made available. The current models of telecommunication networks, which are business and profit oriented, suggest that 5G networks will be mainly deployed in extremely dense urban zones, where the number of subscribers is sufficiently high to compensate the installation and management costs of the 5G net-work [17]. On the contrary, rural areas are less desirable and attractive for operators, since the extremely low-density population does not justify the deployment of 5G networks [17]. Rural areas are only marginally considered in the deployment architectures [16]. Such architectures aim at defining a universal network model that can be applied to cities, towns, and small villages. Nevertheless, the associated costs of these networks are still an open issue. In any case, remote famers, foresters and rural communities are not within the imminent plans of 5G networks [17]. Unlike other technologies, 5G has several advantages that may enable the definition of a holistic 5G architecture explicitly designed to include rural areas [16]. The most important advantages of 5G technology are: (a) the capability of creating Non-Public-Networks that may help to deploy 5G networks dedicated for specific needs of a rural area, (b) capability of 5G deployment based on small cells, which are easier installed in remote rural areas, (c) commodity hardware, which opens the way to the development of software solutions implementing networking functions, and potentially decreasing the costs of installing and maintaining devices [18].

MIMO techniques in 5G In case of rural areas, in which the number of users is not so low, like in the case of forestry, the emerging technology of massive antenna arrays allows the deployment of radio elements covering ultra-large cell sizes (over 50 km). Multiple Input Multiple Output (MIMO) technologies are in the heart of the urban, capacity-driven 5G use cases and scenarios. However, the energy-efficiency of these large antenna arrays is also promising for the noise-limited, low-load rural and remote coverage scenarios [17].

UAVs' role in smart agriculture can be two-fold, operating as a connectivity enabler to remote locations, using the means of 5G, Wifi, creating on spot networks and extending the deployed network setup to even Beyond Line of Sight (BVLOS) scenarios, and as a mobile edge processing server, leveraging GPU and TPU inference on board during flights [16]. Additionally, the adoption of tokenomics as a billing and leasing system, will enable seamless transactions between different stakeholders, e.g., farmers, foresters, community members, technology providers, connectivity providers, with significantly reduced energy consumption [13,15].

Satellites is an alternative means of connectivity, expanding the range of the network [17]. Satellite also has the potential to play a critical role as a middle-mile solution in conjunction with terrestrial options as well as backhaul for terrestrial networks.

Long Range (LoRa) technology has been studied extensively for its growing potential in smart agriculture [19]. It can connect various sensors in the agriculture sector to

the internet for real-time data monitoring and decision-making, enhancing agricultural productivity and efficiency [20]. The convergence of various technologies, such as high altitude platform stations, cloud computing, and LoRa interfaces, can create highly efficient and effective solutions for rural-environment IoT applications [21]. For instance, the use of high altitude platform stations can overcome connectivity limitations in remote and rural areas [22]. Simultaneously, smartphone-based techniques have been explored to extend AI interactions with DIY robots over Wi-Fi and LoRa interfaces [21].

Wi-Fi HaLow, a technology based on IEEE 802.11ah technology, is another promising solution for agricultural environments. It operates in spectrum below one gigahertz (GHz), offering longer range and lower power connectivity [23]. Wi-Fi HaLow can support a very high number of edge devices per Access Point, making it energy efficient and environmentally friendly, and a suitable technology for remote farming, forestry, and rural communities. The enhancement of user experience is at the heart of 5G networks. These networks aim to achieve this through significantly increased data rates and drastically reduced latency times. This will enable services such as high-definition video, tactile Internet, virtual reality, and Internet of Things [24,25].

Rural areas, with their lower population density, are often seen as less appealing for operators, as the deployment of 5G networks can't be easily justified [26]. Nevertheless, 5G has several advantages that could facilitate the design of a holistic architecture that includes rural areas. These advantages include the ability to create Non-Public-Networks for specific rural needs, the possibility of deploying 5G based on small cells, and the use of commodity hardware which could reduce the costs of installing and maintaining devices [27]. Low-cost 5G systems, such as 5G-NPN, have emerged with the advent of Software Defined Radio (SDR) technology, and these could be a viable solution for rural communities [28].

In the case of rural areas like forests, where user numbers are higher, technologies such as massive antenna arrays can be deployed. Multiple Input Multiple Output (MIMO) technologies, central to urban, capacity-driven 5G scenarios, are also promising for rural coverage due to their energy-efficiency [25]. Large antenna arrays can create a beamforming gain, offering similar performance to large macrocells [26]. This allows for an increase in cell radius without compromising implementation complexity, cost-efficiency, or energy consumption.

Furthermore, the integration of these connectivity solutions with artificial intelligence (AI) and machine learning (ML) has the potential to greatly enhance rural connectivity and productivity [23]. AI and ML technologies can optimize the use of resources, predict system performance, automate processes, and analyze large volumes of data to support decision making [24]. For example, AI can be used in smart agriculture to predict crop yield, identify plant diseases, optimize irrigation, and manage livestock [25]. Meanwhile, ML can help optimize network performance and manage the data traffic of the various IoT devices connected to the network [29]. Another interesting approach is the deployment of community networks [27]. These are self-organized and operated networks, where local communities take an active role in their development and maintenance. They often leverage open source software and hardware and are designed to provide affordable, locally controlled internet access [30]. This approach has been successfully implemented in many regions worldwide and can be particularly effective in rural and remote areas where conventional commercial networks are not viable. The implementation of community networks can be further supported by cooperative and peer-to-peer models to share resources and knowledge, fostering local development and digital inclusion [31].

In summary, achieving rural connectivity is a complex challenge that requires a multifaceted approach. It involves not only the deployment of appropriate technologies and infrastructures but also the development of suitable business and governance models, the enhancement of local capacity and knowledge, and the creation of supportive policy and regulatory frameworks [31]. Collaboration between different stakeholders, including

governments, industry, local communities, and academia, is essential to drive innovation and ensure that the benefits of digital technology are available to all [9].

3. Hybrid 5G & Blockchain Architecture for Smart Agriculture Rural Communities

The overall proposed conceptual inter-disciplinary approach can be depicted in Figure 1, where the different layers, stakeholders and directives are inter-connected and interact with each other. The primary ambition of the architecture is the fostering of an inclusive and accessible framework, including a decision support tool, various connectivity and edge technologies, and policy analysis procedures, which will assist and support remote communities, businesses and agro-centric stakeholders to embrace and adopt novel technologies, while building new trusted relations among them on mutual benefits.

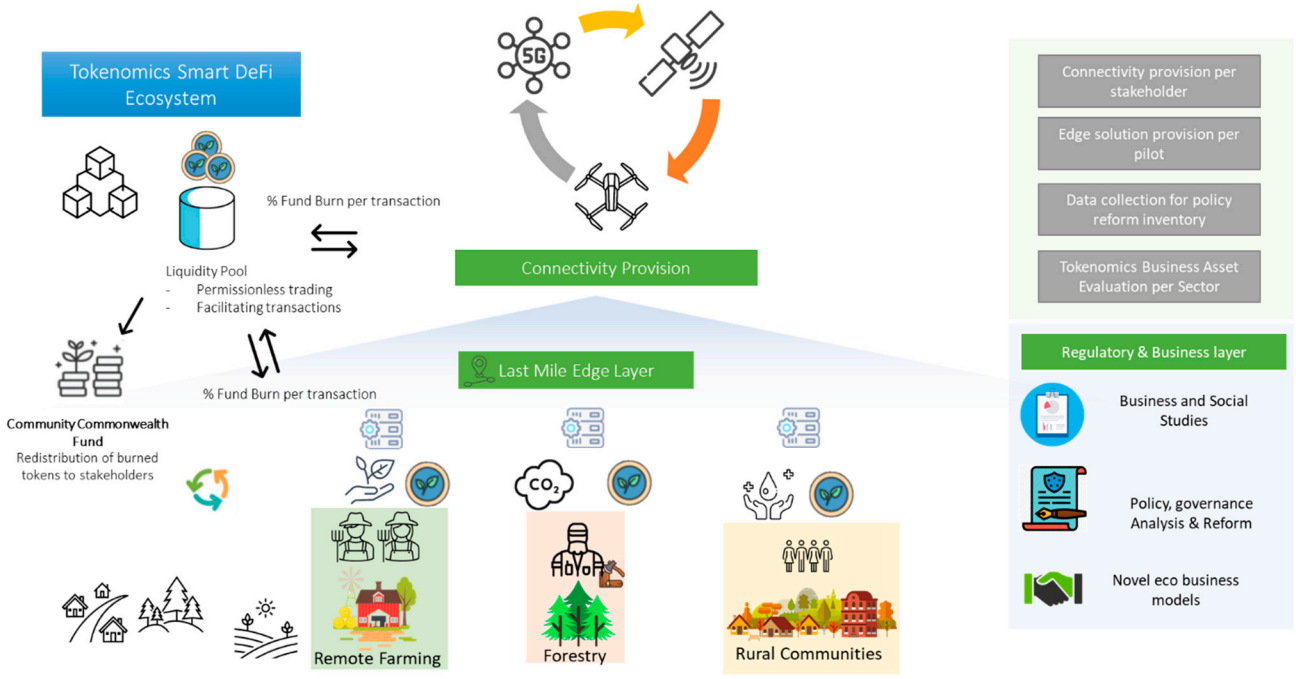

Figure 1. Conceptual overview and tools that benefit the different stakeholders.

The architecture is split over different layers that represent technologies, business, coordination tools, regulatory practices and the end-users' farms, forestries, communities that help develop this multi-actor approach for last mile solutions. More specifically the project's key elements are:

- A decision-making support tool—the DSS, which is the backbone of the process towards faster and smoother adoption of novel 5G technologies in rural and remote areas, taking into account the multi-variant and multi-actor ecosystem that it aims at.
- The regulatory & business layer, which will undertake compliance activities of the current connectivity solutions and provision the necessary actions for full adoption of 5G, satellite, drone and other connectivity alternatives in the rural ecosystem. This layer will also perform the necessary environmental and societal surveys and analysis about the impact that 5G can have in the targeted environments.
- Connectivity provision layer coordinates the networking aspect of remote areas and proposes a converged management method for deployment and provision. Apart from 5G, Satellite and drone extended communications, it introduces a relatively new long range connectivity solution namely WiFi HaLow, based on IEEE 802.11ah technology, which operates in the 750 MHz to 928 MHz band (S1G spectrum). This frequency spectrum offers longer coverage range, making it ideal for rural environments. Furthermore, its low power consumption makes it more environmentally friendly

and its low deployment cost is an advantage for areas where no other connectivity network exist.

- The Last Mile Edge Layer offers the enhanced technology solutions that farmers, foresters and rural community members can benefit from, with a wide set of technologies covering various environmental, production, economic and societal aspects. The edge technologies will be described in detail in the related relevant section, however an indicative set includes vineyard monitoring analysis, edge privacy services, drone assisted pest reduction methods with pesticide usage minimization, forest carbon footprint analysis, and drone supported reforestation techniques.
- Finally, the Tokenomics Smart Decentralized Finance (DeFi) ecosystem introduces the novel concept of tokenomics in the Green Deal and Digital age era, as an evolution of the traditional blockchain based mechanisms, to disrupt, innovate and revolutionize the business perspective of the targeted ecosystem. Tokenomics as a concept can function as an underlying green business and financial layer, totally decentralized, and totally environmentally aware as it does not require any legacy mining procedures to verify its transactions and smart contracts. The proposed concept believes that along with a proposed parametric insurance schema, tokenomics can function as the "bridge" between the different disciplines and actors, and truly create dynamic use cases with true value for a Society 5.0.

Proposed Decision Support Tool

A holistic and dynamic decision support tool is vital for the proliferation of any unified framework that has the ambition to join different disciplinary sectors and provide an automatic process for decision-making and framework assessment. Aligned with the vision to support effectively under-privileged communities, farms and forestries and reducing the technology gap between them and corporate farming, aims to develop a turnkey Decision Support System (DSS), which will incorporate all that we currently expect from a typical DSS in farming applications, with the different innovation layers of 5G VIOLET.

An overview of the different components of the enhanced DSS proposed is represented in Figure 2. Each layer represents a link to the conceptual vision and depicts the preparation and procedural phase that the DSS carries out to export the recommendation, solution provision and analysis to the corresponding stakeholder.

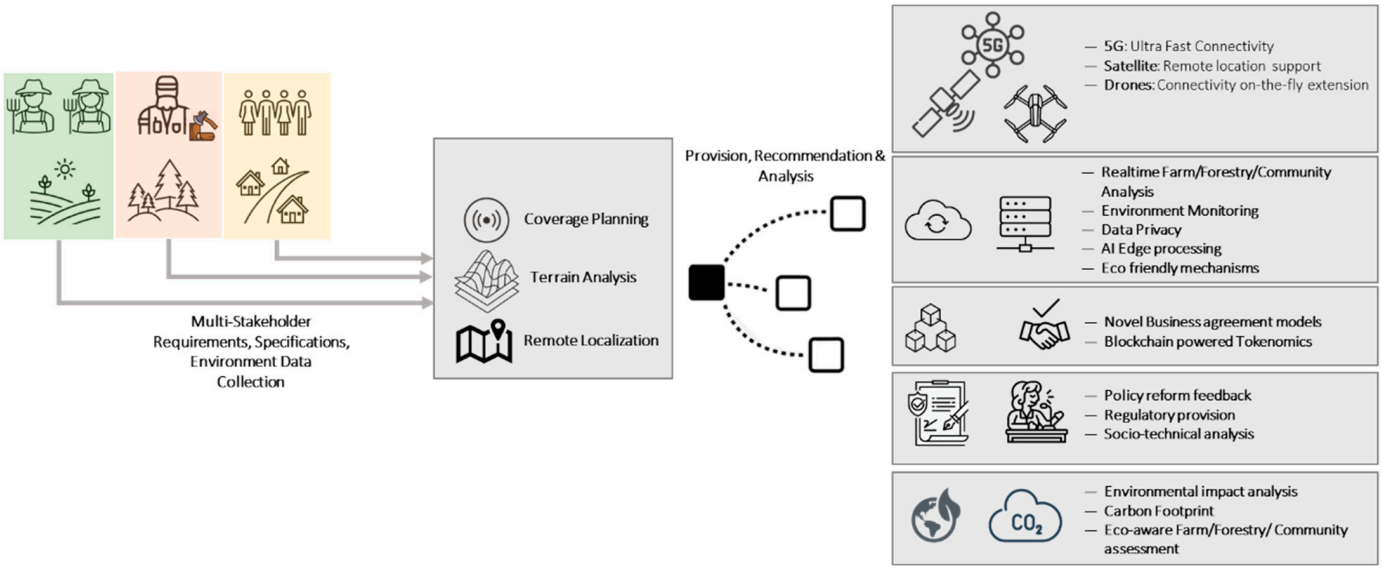

Figure 2. The Multi-disciplinary approach of the proposed framework.

As it can be seen in Figure 2, the core mindset is based on the multi-disciplinary and multi-actor conception, puts the farmers, foresters and community members at the

foundation of the design, decision-making and implementation process. The key points of the DSS can be outlined as:

Multi-Stakeholder requirements, specifications and environment data collection: This step is substantial to the DSS operation, as it collects the necessary information from the targeted end-users and utilizes them as the basis of the design and realization of the technologies, as well as the assessment of these against the policies, regulations and environmental and societal impacts. It is important to underline the stakeholder data collection process as it paves the pathway towards a multi-disciplinary approach placing farmers, foresters and communities at the centrefold of the design and development strategy, with the drive to tackle systemic resilience, create new opportunities and reduce digital divides. In this phase, requirements of the stakeholders, specifications of their technologies and detailed of their environment and premises will be gathered in order to better assess limitations, barriers and provide the suitable technology solutions both in connectivity and edge to maximize their potential.

The next phase consists of the DSS main functionality, where the previously collected data will be processed, and based on them a Coverage Planning (CP), Terrain Analysis (TA) and Remote Localization (RL) analyses will be performed. Coverage Planning will scan the area to automatically detect the available connectivity solutions and generate a map of the related coverage and span across the remote crops, forests and rural communities that will be facilitated. Furthermore, based on the existing coverage an environmental impact analysis will be performed to identify any potential risks and propose eco-friendly alternatives. The Terrain Analysis phase will cover the ground morphology of the region under investigation to identify any potential blind spots and barriers that would render the deployment of certain connectivity solutions challenging, this would also trigger the DSS to compose a hybrid connectivity solution with a converged communication solution. Finally, the remote localization component will perform an analysis on the localization capabilities available in the region under investigation, meaning if GPS, Galileo, etc. are operational in the area.

The final step involves the provision, recommendation, and analysis activities, which are split across the different disciplines.

Initially, the backbone of operations is connectivity, which brings multimodal means of communication to cover a wide range of scenarios and environment conditions, topology and morphology. 5G can offer ultra-fast speeds and the endpoint to interconnect numerous sensors and devices. Satellite communications can offer remote location support in areas where 5G cannot operate due to deployment costs, or multiple blind spots. Drones can be used as a rapid connection extender to cover for a certain time a single or multiple areas. Last but not least, WiFi HaLow are hybrid connectivity open-source solutions that serve as an ad-hoc network deployer, where no prior connectivity setups exist, or have malfunctioned. It envisions these two connectivity solutions to become major players in rural environments, because they are easily deployed, without the need of a large investment, with adequate data rates and coverage ranges and environmentally friendly.

In contrast to the related literature, the proposed conceptual interdisciplinary approach offers a comprehensive model that connects various elements of the ecosystem, extending beyond the confines of individual elements of technology. For instance, Ref. [17] discusses the role of 6G technology in improving m-Health applications, but it doesn't elaborate on how this technology will be integrated into the broader rural ecosystem, a gap that this paper aims to fill. Moreover, while ref. [13] explore the potential of blockchain technology in agri-food traceability, they don't address how this technology can be deployed within an inclusive and accessible framework such as the one proposed here.

In [15] delve into the concept of energy-based economic sustainability protocols, yet, the proposed architecture in this paper introduces the novel concept of tokenomics in the Green Deal era as a decentralized and environmentally aware solution for rural ecosystems, an area not covered in their research. Furthermore, while ref. [19] offer an overview of LoRa for smart agriculture, and ref. [21] provide an implementation of a LoRaWAN-based

decision support system, the present work proposes a multi-layered architecture with various connectivity solutions such as 5G, satellite, drone communications, and WiFi HaLow, delivering a more comprehensive approach. Thus, this paper builds upon and extends the ideas presented in these and other referenced works, offering a broader, more integrated model for rural connectivity and decision-making processes.

4. Tokenomics Powered Business Model

The development of blockchain technologies has led to the development of a new direction in the economy, referred to as crypto-economics or "tokenomics" [10]. In general, crypto assets can be classified into two main categories, according to their principal function: native coins and crypto tokens. Native coins, like Bitcoin, generally compete with the traditional forms of money providing both an alternative currency instrument and a payment infrastructure. Differently from native coins, crypto tokens are coins that embed some intrinsic values somehow linked to the quality of the issuing entity's business model and to the ecosystem it generates [32,33]. Therefore, it worth investigating the creation of a business model for farming, forestry and rural communities based on a crypto token, which will be created for that purpose. The creation of new tokens is generally a less complex process than creating native coins as it does not require to modify the codes from a particular protocol or create a new blockchain from scratch. Moreover, the recent implementation of blockchain middleware and app development tools, Turing-complete codes for smart contracts on the blockchain allow crypto tokens to be easily created, published, shared and exchanged. The introduction of token networks based on blockchain technology in such a dynamic environment as for farmers, foresters and rural communities could represent an additional stage towards a completely disintermediated sharing economy and distributed business models where the lines between users, producers and investors are blurred.

The proposed concept investigates a business plan, where Decentralized Collaborative Commons will expand across different types of last mile networks (5G, satellite) and as access will overcome ownership, competition will be superseded by cooperation, buyers (borrowers) and sellers (investors) will transition to prosumers. Utility tokens will play an active role in this new business model. A consumer (famer, forester, citizen in rural community), who buys a utility token supports the network stability and liquidity. The more purchases and sales of services or goods happen in the network, the more effective the network will be. The use of utility tokens by new users increases the value of the tokens and consequently the investment value of the other users. More importantly, an investor using the utility token will increase the value of its investments while providing a better network for another user. Therefore, the distinction between stakeholders is expected to fade: a customer will be an investor and vice versa. A business company (e.g., related to forestry) based on utility tokens will potentially be favored by a positive escalation effect where use of tokens will benefit users by originating a self-enforcement mechanism. The overall conceptual inter-disciplinary approach can be depicted in Figure 3, where the different layers, stakeholders and directives are inter-connected and interact with each other. The primary ambition is the fostering of an inclusive and accessible framework, including a decision support tool, various connectivity and edge technologies, and policy analysis procedures, which will assist and support remote communities, businesses and agro-centric stakeholders to embrace and adopt novel technologies, while building new trusted relations among them on mutual benefits.

The ever-evolving economic and environmental landscape [34,35] has created a significant digital and business scale gap between corporate entities and smaller businesses and communities. This aspect is further amplified when the farm, forestry, community is also remotely located, far from the telco fast broadband backbone. Last-mile investments are always expensive and an insurmountable cost for the stakeholder to bear. The model proposes a multi-actor business to nourish and foster last-mile services-as-a-whole, while proposing budget friendly solutions, and novel data monetization [36,37]. Nowadays, small farmers, foresters, communities technically give away their data in exchange for

limited analytic insights [38,39]. The concept acknowledges that especially remote farms, forestries and communities have vastly more unique data to offer, due to their location, and the atypical weather patterns they experience. This data possesses significant value for several stakeholders, either scientifically, or environmentally, or even financially. Therefore, the project proposes a decentralized mechanism to monetize this type of data and reinforce the market position of the farmers, foresters and rural communities.

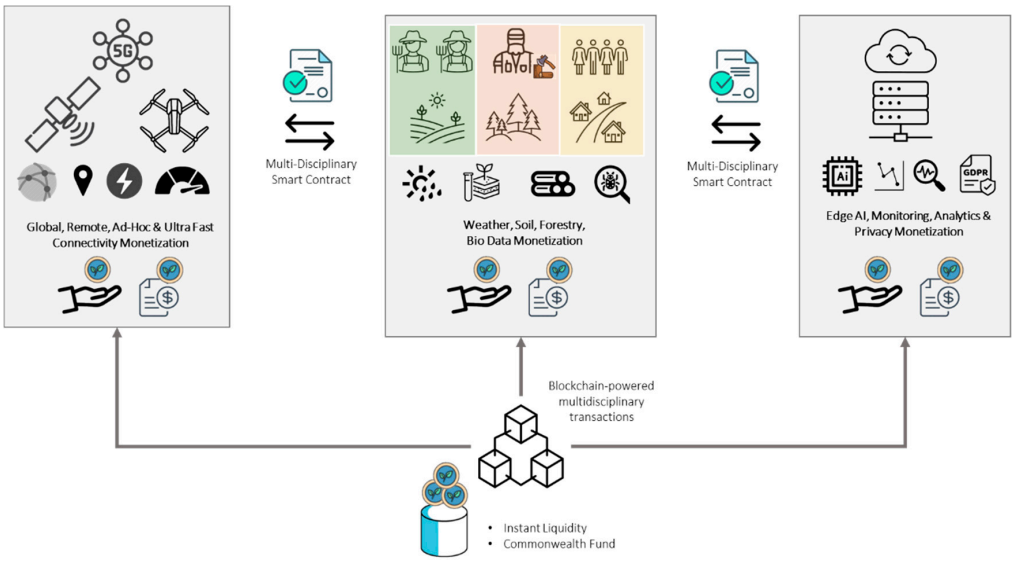

Figure 3. Tokenomics based business model overview.

The proposed mechanism is based on an implementation of the tokenomics paradigm, which is technically a layer-2 evolution of common blockchain solutions. Tokenomics contrary to legacy mechanisms adopt a deflationary approach, where all tokens are already issued in a large quantity, thus bypassing the need for mining new "value", which is the reason they are also an eco-friendly alternative financial foundation. Tokenomics support all the enhanced functionality of blockchain mechanisms, including smart contracts, which will be used to realize multi-disciplinary novel business agreements.

Tokenization, as an alternative to Proof-of-Work (PoW) in blockchain technology, addresses key challenges such as high energy consumption and scalability issues. PoW's mining process, which validates and records transactions on the blockchain, requires substantial computational power and energy. This has raised environmental concerns due to its carbon footprint. In contrast, tokenization doesn't require mining, making it more energy-efficient. Instead of miners, tokenization systems can use consensus mechanisms like Proof of Stake (PoS) or Delegated Proof of Stake (DPoS), which require less computational power.

In terms of scalability, PoW-based blockchains often struggle due to the fixed time it takes to add a new block to the blockchain. This can lead to delays and high transaction fees when the network is busy. Tokenization can help address this issue by enabling faster transaction times and lower fees. Transactions can be processed off-chain or use sharding techniques to increase the number of transactions that can be processed simultaneously. Tokenization also offers security advantages. While PoW is secure, it's vulnerable to a 51% attack, where a single entity gains control of the majority of the network's mining power, allowing them to double-spend coins. Tokenization systems often use consensus mechanisms that make a 51% attack more difficult and costly. Furthermore, tokenization can be more inclusive, allowing anyone to participate in the network and earn rewards, regardless of their computational power. However, it's important to note that while tokenization can address some of the challenges associated with PoW, it also comes with its own set of challenges, such as the need for robust smart contract security and the potential for increased centralization in some consensus mechanisms.

Furthermore, rural business and community reinforcement will be two-fold, firstly data generated in them will gain exponentially in value by the decentralized and turnkey mechanism used to make it available, and secondly by the proposed tax implementation, which will allocate a percentage of its transaction's value to commonwealth fund, to be further invested in the rural economy. Thus, the project proposes a circular and sustainable economic model for rural businesses and communities to monetize data assets currently undervalued and underappreciated, while providing them an ecosystem of last-mile connectivity and edge services easily accessible and budget friendly tailored to their needs and requirements.

The tokenomics model can be applied in a holistic manner, covering also the connectivity and edge domains. Regarding, last-mile connectivity solutions depending on the technology a specifically tailored data billing model will be designed and implemented in order to generate volume for the ecosystem and a considerable revenue stream for the commonwealth fund. In this model, all the proposed connectivity solutions will play a pivotal role in the development of a multi-device, multi-sensor environment with inherent service monetization functionalities.

Parametric Insurance Powered by Tokenomics

Financial independence and increase competitiveness for agricultural, forestry sectors and rural areas can be gained through a sustainable business model that not only increases profits and production but also protects them against outlier events and incidents. The proposed concept identifies asset protection and insurance as a crucial factor in the development of under privileged areas and communities and proposes a hybrid model of dynamic parametric insurance with the integration of tokenomics. Parametric insurance (sometimes referred to as index-based insurance) is a type of insurance that does not indemnify or compensate for the actual loss, but rather issues a fixed payment upon the occurrence(s) of an objective triggering event, contrary to the common indemnity insurance. Parametric insurance—or warranties as some like to refer to it—has been used to complement indemnity products as a 'front stop' to get payments out quickly to insureds before full loss assessments are obtained. Additionally, farmers, foresters and other rural sectors in developing communities often lack access to insurance because of the low margins for insurers. The project directly addresses this gap and proposes a novel approach which will further converge with the whole vision for a sustainable and circular Society 5.0. The overview of the proposed model is presented in Figure 4.

In the proposed model, aligned to the multi-disciplinary philosophy different stakeholders will be able to insure different physical and digital assets on blockchain-backed smart contract with variant insurance parameters according to each case. The edge monitoring framework can provide real time seamless provision of the farm, forestry, community assets and at the same time observe external sensors attached to various environment parameters related to the sector each time. When a parameter condition is satisfied, the smart contract policy is automatically enforced and the policyholder, in this case the farmer, forester, other community member, receives the predefined pay-out instantly. The proposed mechanism and introduction of the tokenomics mechanism, which brings onboard several perks to accommodate the rapid reimbursement of the policy holder. These merits include automatic pay-out backed by the liquidity pool of the token framework, in order to seamless process compensations upon detection. This can benefit the entire multi-actor ecosystem, as it will provide liquidity and accelerate the processing of various procedures, simplifying practices and saving time and money.

While tokenization indeed presents several advantages over traditional systems, it is not devoid of challenges. Tokenization, especially when applied in a blockchain context, relies heavily on the strength and security of the underlying technology. The security of a token-based system is largely dependent on the smart contract platform it is built on, the integrity of the initial token distribution, the consensus mechanism used, and the encryption technologies implemented. Smart contracts, which facilitate the creation

and management of tokens on a blockchain, are typically written in code and can contain vulnerabilities that could potentially be exploited by malicious actors. The smart contract must be thoroughly audited and tested for security flaws before any tokens are issued. Moreover, the code should be open-source and peer-reviewed to ensure it meets industry standards for security and reliability. The consensus mechanism used in the blockchain also plays a pivotal role in securing the tokenization system. As mentioned earlier, systems like Proof of Stake (PoS) and Delegated Proof of Stake (DPoS) are commonly used but also bring their own unique security concerns. It's also worth noting that the blockchain's overall security is a critical factor since a compromise in the blockchain can jeopardize the tokens built on top of it. The initial distribution of tokens is another potential vulnerability in a token-based system. An inequitable distribution of tokens can lead to a concentration of power and wealth, which can result in centralization and potential manipulation of the system. Further, since tokens represent real-world assets or rights, their security is closely tied to the integrity and security of the encryption technologies used to protect them. Advanced cryptographic techniques are required to ensure the safety and privacy of the tokens. In conclusion, while tokenization brings exciting prospects for various sectors, including agriculture and rural communities, it is essential to critically examine its technical details and limitations. Future research and development should aim to address these challenges to fully harness the potential of tokenization in building robust, secure, and equitable systems.

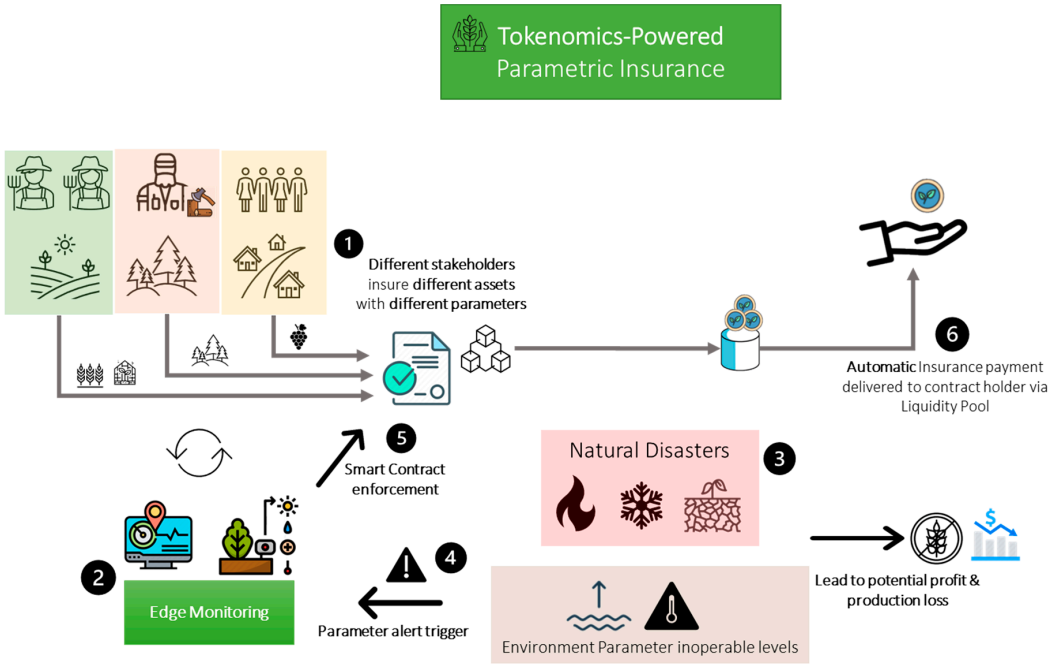

Figure 4. Parametric insurance powered by Tokenomics overview.

The presented framework can also be designed and implemented to interoperate with the rest of the ecosystem and leverage the capabilities and functions offered by the connectivity technologies and the edge layer. The holistic approach on inter-disciplinary business operations can serve as a catalyst for rural development for a variety of sectors and actively close the gap between underrepresented communities and urban, more technology proficient businesses.

The table below provides a comparative overview of the novel UAV-5G system for rural connectivity proposed in this study and the related works identified in the literature. The listed references explore various technological advances, such as 5G and 6G, IoT, unmanned devices, blockchain, and sensor systems, with a particular focus on rural and agricultural applications. The table indicates the key area and idea of each reference, as well as their similarities and differences with the proposed UAV-5G system. It's important to

note that these comparisons are based on inferred content from the titles and years of these references. A thorough reading of these works would provide a more in-depth comparison.

Reference	Key Area	Key Idea	Similarities with UAV-5G System	Differences with UAV-5G System
[12]	6G Technology in m-Health Applications	Discusses the potential role of 6G in enhancing quality of experience for m-Health multimedia applications.	Both highlight the potential of advanced connectivity (5G/6G) in specific applications.	The proposed work focuses on 5G and rural connectivity, rather than 6G and m-Health applications.
[13]	Blockchain in Agri-Food Production and Supply Chains	Explores the role of blockchain technology in traceability systems for agri-food production and supply chains.	Both discuss technology advancements in the agricultural domain.	The proposed work focuses on 5G connectivity, not on blockchain.
[20]	High Altitude Platform Stations for Rural IoT Applications	Discusses cloud-computing solution for rural IoT applications aided by high altitude platform stations.	Both focus on solutions for rural connectivity.	The proposed work utilizes UAVs and 5G technology, not high altitude platform stations.
[18]	Intelligent Agricultural IoT Based on 5G	Discusses IoT in agriculture based on 5G technology.	Both emphasize the role of 5G in advancing agricultural practices.	The proposed work incorporates UAVs into the 5G-enabled IoT solution for agriculture.
[23]	Precision Agriculture and Sensor Systems in Colombia through 5G Networks	Discusses the application of 5G and sensor systems in precision agriculture in Colombia.	Both discuss the role of 5G in enhancing agricultural practices.	The proposed work focuses on the integration of UAVs in the 5G-enabled system.
[26]	Unmanned Agricultural Tractors in Private Mobile Networks	Discusses the use of unmanned agricultural tractors in private mobile networks.	Both consider unmanned technologies in agricultural practices.	The proposed work utilizes UAVs for network connectivity, not for direct agricultural operations.
[27]	The Framework of 6G Self-Evolving Networks and the Decision-Making Scheme for Massive IoT	Presents a framework of 6G networks for IoT applications.	Both emphasize advanced connectivity technologies (5G/6G) in the context of IoT.	The proposed work focuses on 5G and rural connectivity, not on 6G and IoT decision-making schemes.
[28]	Potential Applications of 5G Network Technology for Climate Change Control	Discusses potential applications of 5G technology for climate change control.	Both highlight the potential of 5G technology in addressing real-world issues.	The proposed work is centered around rural connectivity, not climate change control.
[9]	Blockchain Token-Based Quality Management	Introduces a quality management method using blockchain tokens.	Both propose technology-driven solutions for rural and agricultural applications.	The proposed work involves UAVs and 5G technology, not blockchain tokens.
[38]	Wireless Sensor Networks for Monitoring Humidity and Moisture	Discusses wireless sensor networks for monitoring humidity and moisture environments.	Both propose wireless technology solutions for monitoring purposes.	The proposed work involves UAVs and 5G technology, not specific sensor networks for humidity and moisture monitoring.

5. Proof of Concept: UAVs Providing Internet Connectivity to Rural Areas

UAVs have been considered to provide Internet connectivity in rural areas. However, the weight of the equipment onboard the UAV imposes some limitations. In general, the equipment on board the UAV consists of an access network, usually a WIFi or a 4G/5G small cell, which provides connectivity to the user terminals on the ground in its coverage area. The access network requires a backhaul link with an Internet provision node on the ground. This extra backhaul increases the weight of the payload for the UAV.

The use of 5G technology is advantageous because it provides high bit rates and low delays to the end users. With the advent of the NPNs, small scale 5G networks have appeared in the market. An example is the AMARISOFT Call Box which is a complete 5G network running in a PC, equipped with the appropriate SRD cards. It includes both the 5G core and the gNodeB. A light version of AMARISOFT (Call Box mini) weights about two kilograms and it is ideal for onboarding it on a UAV, with the appropriate accessories (battery, antennas). However, it requires a backhaul from the UAV to a ground node, that will provide the Internet connectivity. Any type of backhaul will increase the weight of the load onboard the UAV.

In this paper, we propose an architecture, where a complete lightweight 5G system is installed on board the UAV, which serves a number of user equipment (UE) on the ground. In the proposed architecture, one of the UEs will act as a connection gateway (node UE) of the system to the Internet. In order to achieve the routing of the IP packets from the UEs to the node UE, a lightweight router (e.g., a raspberry) must be on board the UAV. It will

be connected to the Internet connection port of the 5G core and will run appropriate IP table routes.

In the proposed architecture, an IP packet from a UE towards the Internet will reach the 5G NPN on board the UAV and will arrive at the router. According to the IP table routes, the packet will be routed to the IP of the node UE acting as internet gateway of the system. This UE will route the packet to the Internet. The reply will arrive at the same node UE and will eventually reach the router on board the UAV. Following the appropriate IP routing rules, the packet will be directed to the UE that has made the initial request.

Table 1 shows the measurements of downlink and uplink bit rates and RTT (round trip time), for various RSRP (Reference Signal Received Power) levels for the UE and the node equipment and for three TDD schemes. TDD_1 allocates 7 time slots for DL, 2 time slots for UL (per symbol), TDD_2 allocates 6 time slots for DL and 3 time slots for UL, while TDD_3 allocates equal number of time slots for DL and UL. The symbol period of TDD_1 and TDD_2 modes is 5 ms, while for TDD_3 is 2.5 ms. It is obvious that the maximum downlink or uplink bit rates of the UEs is limited by the uplink bit rate of the node UE.

Table 1. DL/UL measurements for different UE and Node RSRP values per TDD schemes.

RSRP UE (dBm)	RSRP Node Equipment (dBm)	TDD_1			TDD_2			TDD_3		
		Downlink	Uplink	RTT	Downlink	Uplink	RTT	Downlink	Uplink	RTT
−75	−75	35.46	41.54	34.79	54.89	61.14	27.89	68.23	72.07	25.52
−75	−90	31.43	35.30	35.93	51.33	53.77	26.64	59.93	66.32	27.59
−75	−100	31.10	33.47	29.58	45.09	40.97	27.01	52.34	49.11	29.12
−90	−75	34.04	29.97	34.31	54.23	58.30	26.29	65.32	64.53	22.34
−90	−90	34.81	38.04	26.46	53.28	54.51	28.19	58.34	62.47	29.18
−90	−100	28.22	21.61	30.86	41.67	42.00	26.86	64.49	50.71	26.68
−100	−75	28.22	17.01	29.85	50.77	35.01	28.80	52.28	41.60	25.36
−100	−90	33.79	14.58	23.49	39.66	37.59	27.75	51.01	35.46	25.06
−100	−100	20.77	11.38	30.51	31.58	15.74	28.78	21.95	21.23	25.77

For comparison reasons Table 2 shows the downlink and uplink bit rates and RTT of the 5G system used.

Table 2. Benchmark 5G testbed DL/UL measurements per TDD schemes.

	TDD_1			TDD_2			TDD_3		
	Downlink	Uplink	RTT	Downlink	Uplink	RTT	Downlink	Uplink	RTT
−75 db	137.93	40.61	12.72	116.42	63.73	13.45	91.5	82.79	12.68

From Table 1 it can be verified that the downlink and uplink bit rates are almost the same and equal to the uplink bit rate that the system can support. It can also be seen that the maximum bit rates for both dL and UL are achieved for TDD_3, where the time slots allocated for downlink and uplink are equal. For the system under testing the maximum bit rates reach about 70 Mbps.

The proposed architecture of installing a lightweight 5G system on board a UAV to serve user equipment (UE) on the ground presents a unique business opportunity. This approach can significantly reduce the cost and complexity of providing internet connectivity in rural and remote areas. Traditional methods of providing connectivity, such as laying cables or building towers, can be prohibitively expensive and logistically challenging in these areas. By using UAVs equipped with lightweight 5G systems, service providers can bypass these obstacles and deliver high-speed internet access to underserved communities. This can open up new markets for service providers and stimulate economic growth in these areas. Moreover, the use of a UE as a connection gateway to the internet further

reduces the weight and power requirements of the UAV, potentially leading to longer flight times and larger coverage areas. This innovative approach can give service providers a competitive edge in the rapidly evolving telecommunications market. It also aligns with the trend towards network decentralization, where end-users play a more active role in the network.

Delving deeper into the results, we see that the 5G system onboard the UAV, when subjected to various RSRP levels for the UE and node equipment, shows consistent performance across the different Time Division Duplex (TDD) schemes. The measurements of downlink and uplink bit rates and RTT confirm the robustness of the proposed architecture. More specifically, the results demonstrate that the maximum downlink or uplink bit rates of the UEs are limited by the uplink bit rate of the node UE, which is crucial for optimal performance. When comparing the downlink and uplink bit rates and RTT of the used 5G system, the results indicate near parity between the downlink and uplink bit rates, thus confirming that the system can support such levels effectively. Furthermore, TDD_3, where the time slots allocated for downlink and uplink are equal, produces the maximum bit rates for both downlink and uplink, reaching up to about 70 Mbps. This clearly showcases the potential of the proposed architecture in handling high data rates, which is a key requirement for providing reliable internet connectivity.

Turning to the configuration of the UAV used in the study, it is a PX4-based drone. The PX4 platform is known for its robustness and flexibility, making it ideal for this application. The UAV is configured to fly at an optimal height, i.e., ~120 m, which is determined by factors such as the terrain of the area and the range of the 5G system. It has been designed to have sufficient power to carry the 5G system while maintaining a stable flight. The type of the UAV and other specific characteristics are chosen based on factors like the weight of the 5G system, the flight duration needed, and the size of the area that needs coverage. The proposed architecture, in effect, transforms the UAV into a flying 5G base station. With the PX4 platform's well-established reliability and the lightweight nature of the onboard 5G system, the UAV can effectively provide internet connectivity to remote or underserved areas. The ability to route IP packets from multiple UEs to a single UE acting as an internet gateway further optimizes the system, reducing the weight and power requirements of the UAV and potentially extending flight times and coverage areas. In conclusion, the proposed architecture not only showcases a promising solution to the technical challenge of rural connectivity but also highlights a potentially lucrative business opportunity in the telecommunications sector.

Finally, the proposed architecture can also create opportunities for other businesses. For instance, companies that manufacture lightweight 5G systems or develop UAV technology may see increased demand for their products. Similarly, businesses that provide services related to UAV operation and maintenance, such as drone pilot training or UAV fleet management, could also benefit. In summary, the proposed architecture not only addresses technical challenges but also presents significant business opportunities in the telecommunications sector and beyond.

6. Conclusions

This paper has introduced an innovative smart agriculture platform that leverages the power of 5G technologies and the tokenomics paradigm, aiming to revolutionize current architectures for smart and energy-efficient farming. Unlike similar studies, this work delves into a comprehensive range of open challenges in the field, offering a diverse array of integrated solutions and applications. A unique aspect of this work is the conceptual framework for parametric insurance, demonstrating how it can be enhanced through the use of blockchain technology and tokenomics. This approach provides a fresh perspective on how to manage risk and uncertainty in the agricultural sector, offering potential benefits for farmers and insurers alike. The paper also presents experimental tests for a drone-assisted 5G connectivity scenario, underscoring the feasibility of using drones to provide connectivity services in rural and remote areas. These tests demonstrate that

the proposed system can support adequate network speeds under various mobility and location conditions, setting it apart from other studies in the field.

The key contribution of this work is its innovative approach to addressing the challenges faced by remote farmers, using cutting-edge technologies from various fields. Looking ahead, the platform will be tested in real-world scenarios, providing valuable insights into how dynamic technology solution integrations can transform the future of smart agriculture.

Moving forward, one of the primary future steps involves deploying and evaluating the proposed smart agriculture platform in real-world scenarios. This necessitates close collaboration with farmers and other stakeholders in rural and remote areas to understand their specific needs and challenges. The platform will be tested under various conditions to assess its performance, reliability, and user-friendliness. Feedback from these trials will be invaluable in refining the platform and ensuring it delivers tangible benefits to its users. Another important future step is exploring dynamic technology solution integrations. This could involve integrating the platform with other emerging technologies such as artificial intelligence, machine learning, and Internet of Things (IoT) devices to further enhance its capabilities. For instance, machine learning algorithms could be used to analyze data from the platform and provide insights to help farmers make more informed decisions.

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