Precision Agriculture and Sensor Systems Applications in Colombia

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The growing global demand for food and the environmental impact caused by agriculture have made this activity increasingly dependent on electronics, information technology, and telecommunications technologies. In Colombia, agriculture is of great importance not only as a commercial activity, but also as a source of food and employment. However, the concept of smart agriculture has not been widely applied in this country, resulting in the high production of various types of crops due to the planting of large areas of land, rather than optimization of the processes involved in the activity. Due to its technical characteristics and the radio spectrum considered in its deployment, 5G can be seen as one of the technologies that could generate the greatest benefits for the Colombian agricultural sector, especially in the most remote rural areas, which currently lack mobile network coverage.

5G agriculture Colombia smart farm spectrum sustainability

1. Introduction

According to the Food and Agriculture Organization of the United Nations (FAO), agriculture “is a manmade activity to produce food that meets the needs and food security of the people of a given population” [1]. Agriculture is the main food source for the world’s population and represents an economic income for developing countries through its exports. Although it generates these benefits, current World Food Program estimates indicate that approximately 690 million people in the world suffer from hunger, forcing the United Nations (UN) to prioritize within the Sustainable Development Goals (SDGs) an increase in agricultural productivity and sustainable food production to alleviate the risk of hunger.

The inclusion of technologies could contribute to the fulfillment of SDG 2 “end hunger”, projected in the 2030 agenda by the UN through the strengthening of agricultural processes to meet the food needs of the world’s population. Some relevant technologies to contribute to this goal of strengthening agricultural processes are smart agriculture (SA), precision agriculture (PA), 5G, and the Internet of Things (IoT), which can be scaled up in developing countries such as Colombia to strengthen agriculture.

In Colombia, there are crops of great importance, not only for the food sustainability of its population (e.g., rice, cassava, avocado, and corn) but also for other activities such as ornamental flowers, or cassava, used as raw material in the production of starch. Many of these plantations cover large geographical areas or are located far from the main municipalities, making their control and management difficult. In this sense, future 5G deployments could become an excellent opportunity for Colombian growers to optimize their operations, from the initial planning stage of the plantation to the final commercialization of their production.

2. Agriculture 4.0

Talking about Agriculture 4.0 or digital agriculture (DA) implies knowing its evolution through time (see **Figure 1**). The first agricultural methods used papyrus to develop irrigation systems such as those used by the Egyptians and Greeks around 6000 BC [2], which depended on human labor and animal power [3]. During the 17th century, the era of feudalism emerged on the European continent, including new agricultural treatment techniques, and the incursion of machinery for soil treatment, sowing, weeding, irrigation, and harvesting [4].

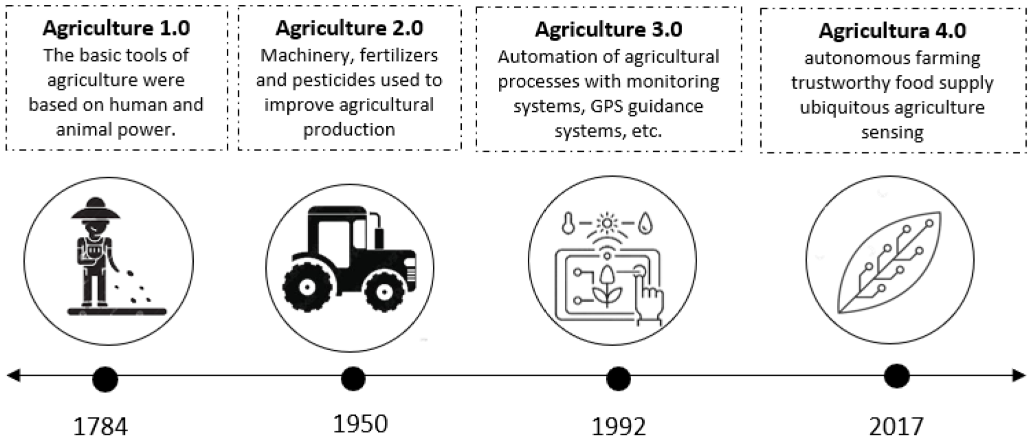

Figure 1. Timelines of agricultural revolutions (based on [3]).

As agriculture is one of the most important economic pillars in the economy of countries, it needs to adopt new technologies such as PA, which apply inputs in the right place at the right time [5]. In this context, large economies around the world are applying PA to improve agricultural processes for products that contribute significantly to economic development. For example, China and India have been applying PA to increase tea crop yields for more than a decade. Similarly, in Malaysia, it is being used to optimize crop-specific fertilization techniques [6]. These successful experiences and others reported in the literature, provide a glimpse of some PA application scenarios that can serve as a reference for other countries where agriculture is important for the economy and food sustainability.

According to data from the Food and Agriculture Organization of the United Nations (FAO), in Colombia, between 20% and 40% of crops are lost due to little or no treatment of diseases and pests, resulting in losses of more than six million tons per year. The technological incursion in the Colombian agricultural sector has been progressive, with a predominance of artisanal methods, which of course have repercussions for the production of products with qualities that are not very competitive in international markets [7]. To achieve improvements in the quantity and quality of agricultural products, it is necessary for growers to introduce new technologies that integrate wireless sensor networks (WSNs) for crop monitoring and enable analysis of data collected by the WSNs [8].

In the last two decades, the advancement and innovation of science and technology in the sectors of telecommunications, electronics, software development, and AI have played a prominent role in what is now called SF [4].

3. Smart Farming (SF)

SF focuses on the application of good agricultural practices combined with the implementation of different emerging technologies, improving crop quality and production [9]. Some examples of applications are related to disease monitoring at planting [10] and control of crop variables [11][12][13]. Its objective is productive efficiency, yield, profitability, and mitigation of environmental impact through the implementation of different techniques such as intelligent irrigation and precision in the application of pesticides and fertilizers [14].

SF brings together different technological developments, including AI, big data (BD) [15], and IoT [16]. These help in the solution of the problems and challenges currently faced by the agricultural sector, especially the requirements of increased food production due to the growth of the world population [9], which, according to UN predictions, will reach 8.5 billion people in 2030, 9.7 billion in 2050, and 11.2 billion in 2100 [17]. Another challenge for SF is to reduce the digital divide in rural areas [18], which are generally correlated with low income levels. It is estimated that 40% of the world's population lives in developing countries (e.g., Colombia and other Latin American countries) [19]. SF would drive important changes in social and economic structures, testifying to the rural population [20], and fostering private sector and government policies to strengthen efficiency and agro-industrial production. Another major challenge of SF is related to the efficient management of water, a vital resource in agriculture. This activity consumes 70% of the world's freshwater, and 20% of the total cultivated areas are irrigated [21].

Most of the SF applications obtain information on physical variables in agricultural land, using IoT sensors that favor food production from collected data [22]. IoT allows monitoring of all processes involved in agro industrial production, automating control tasks for efficient production [23]. The massification of FS includes the joint work with telecommunications access networks that support the connections of a large number of sensor nodes. Generally, the captured data are analyzed by machine or deep learning algorithms, requiring stable connections, bandwidth with high speeds, and very low latencies that could not be supported by current third- and fourth-generation networks (3G and 4G) [24]. Therefore, fifth-generation (5G) networks promise to leverage the implementation of SF in population power demand.

4. 5G Usage Scenarios

The International Telecommunication Union (ITU), in its recommendation ITU-R M.2083-0, defined the framework and general objectives for the future development of International Mobile Telecommunications (IMT) for the year 2020 and beyond, establishing the role of IMT in developed and developing countries to meet and enhance the future needs of an interconnected society. The authors of [4] summarized the role of IMT in three scenarios, as shown in **Figure 2**.

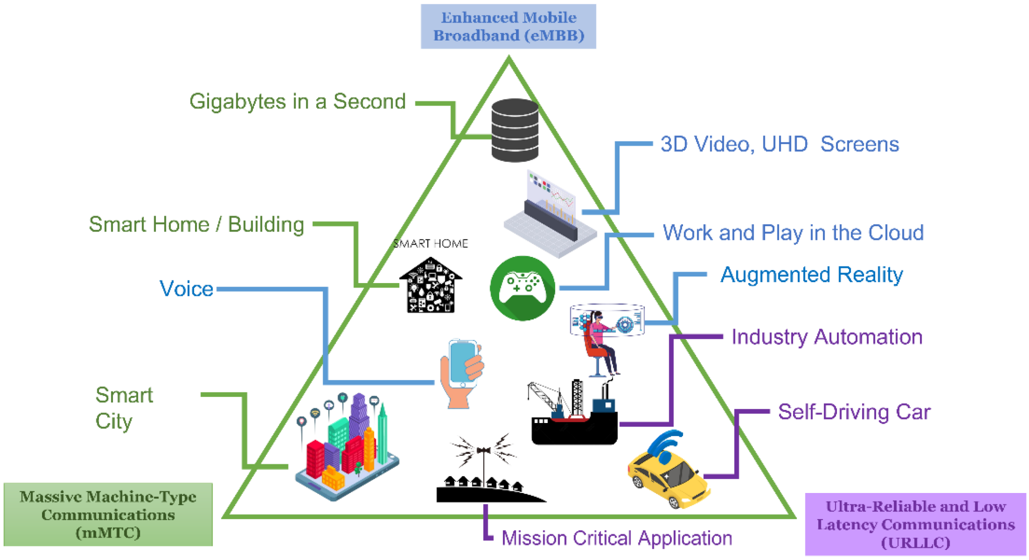

Figure 2. IMT scenarios for 2020 and beyond. Source: [4][25][26].

Figure 2 presents three scenarios defined by IMT: (1) enhanced mobile broadband (eMBB), focused on multimedia services consumption, (2) ultrahigh reliability and low latency (uRLLC), focused on industrial and emergency mission applications, and (3) massive machine type communications (mMTC), oriented to massive device connection (more than one million devices per km^2). The above scenarios have different types of requirements, including high bandwidth, low latency, and capacity to support massive device connections. eMBB applications base their services on the cloud, virtual reality, and augmented reality, demanding greater network resources. On the other hand, uRLLC is in great demand for services and applications that require low latency and reliability in machine-to-machine (M2M) communications. Examples of uRLLC applications are autonomous cars, industrial communications, and intelligent electrical networks. In the case of the mMTC scenario, it is oriented to support the massive growth of connected devices, the product of IoT-based applications. Lastly, all these implementation scenarios are addressed in terms of the benefits of 5G.

5. 5G Frequency Bands and Their Applications

The “5G Spectrum” report presented by the Global Mobile Industry Association (GSMA) states that three key spectrum ranges are needed for 5G to support all use cases. The first corresponds to the frequency band below 1 GHz. This portion of the spectrum is an excellent option for extending 5G coverage in urban and rural areas since it has lower signal attenuation. In addition, the sub-GHz bands are a great support for the communication of IoT-based technologies. Some use cases of this band are found in Europe, where the 700 MHz band is used, and in the United States, where the 600 MHz band is used, both supporting 5G services. The next range (between 1 and 6 GHz) offers a very good ratio between coverage and capacity for 5G services. Some countries (e.g., Spain, Germany, and Japan) auctioned this frequency range to deploy 5G services. Lastly, frequencies above 6 GHz are necessary because they handle ultrahigh speeds provided by the available bandwidth, supporting uRLLC and enhanced broadband services [27]. **Table 1** summarizes the frequency bands used in the agro-industrial sector and their main characteristics.

Table 1. The 5G spectrum bands and their applications [28][29].

Band range	Typical Spectrum Types	5G App1	5G App2
<1 GHz	600 MHz, 700 MHz, 800 MHz, 900 MHz	Rural/unlicensed	Urban, WLAN(IoT)

Band range	Typical Spectrum Types	5G App1	5G App2
1–6 GHz	1800 MHz 3.3–3.8 GHz	Urban/unlicensed	IoT/ITS
>6 GHz	(6–28 GHz)—24 GHz, 26 GHz, 28 GHz	UWB wireless fiber	Wireless VOD

3. Projected 5G Frequency Bands in Colombia

Table 2 describes the status of the radio spectrum frequency bands in Colombia, including frequency bands, uplink, downlink, the status of use, availability, and operators that have been granted radio spectrum use permits. Regarding the assignment of operators, the Ministry of Information and Communications Technologies (MinTIC) issued nine resolutions assigning radio spectrum use permits for the 700 MHz and 2500 MHz bands to the following operators for the deployment of 4G telephony and internet services: Colombia Móvil S.A. (Tigo), Comunicación Celular. S.A Comcel.SA (Claro), and Partners (Wom).

Table 2. Status of 5G band projections in Colombia.

Band Range (MHz)	Total, Free Spectrum in Band (MHz)	Uplink (MHz)	Downlink (MHz)	Status	Operator	Reference
600	70	663–698	617–652	Available in March 2029	-	[30]
700	10	703–748	758–803	Before September 2022 (auction). For 4G use, most of this frequency band was licensed in December 2019.	Colombia Movil S.A (Tigo) (713–723 MHz couplet with 768–778 MHz) and (703–713 MHz couplet (758 MHz–768 MHz) Partners (Wom) 723–733 MHz couplet with (778–788 MHz. Comunicación Celular. S.A Comcel.SA (Claro) 733–743 MHz couplet with 788–798 MHz)	[31][32][33][34][35][36][37][38][39][40][41][42][43][44][45]
1900	5	1850–1910	1930–1990	For 4G use, most of this frequency band was licensed in December 2019.	Established for IMT with no regulations in force for its use.	[32][33][34][35][36][37]
2500	30	2500–2570	2620–2690	Before September 2022 (auction). For 4G use, most of this frequency band was licensed in December 2019.	Partners (Wom) 25154–(2520 MHz, couplet with 2635–2640 MHz) Comunicación Celular. S.A Comcel.SA (Claro) (2550–2555 MHz couplet with 2670–2675 MHz) (2545–2550 MHz 2665 couplet with 2670 MHz) (2540–2545 MHz 2660 couplet with 2665 MHz)	[33][34][35][36][37][38][39][40][41][42][43][44][45]
3500	400	3300–3700 (Canalization TDD)		Study auction	Unassigned operator	[30]
26,000	1000	24,250–27,500		Available in 2027	Unassigned operator	[27][45]

Colombia currently uses the 700 MHz, 1900 MHz, and 2500 MHz bands with 2G, 3G, and 4G services. Up until the fourth quarter of 2021, 4G infrastructure deployment reached 95.34% coverage in municipalities with fewer than 100,000 inhabitants and 99.77% in municipalities with more than 100,000 inhabitants, as shown in **Figure 3**. However, it has been evidenced by MinTIC that, of the total number of active mobile telephony lines, 51% only use voice services without going beyond the navigation service, and that 21% of the total mobile internet accesses in the country are made through 2G and 3G technologies, especially in rural areas, limiting the features and benefits in terms of data transmission speeds offered by 4G [46].

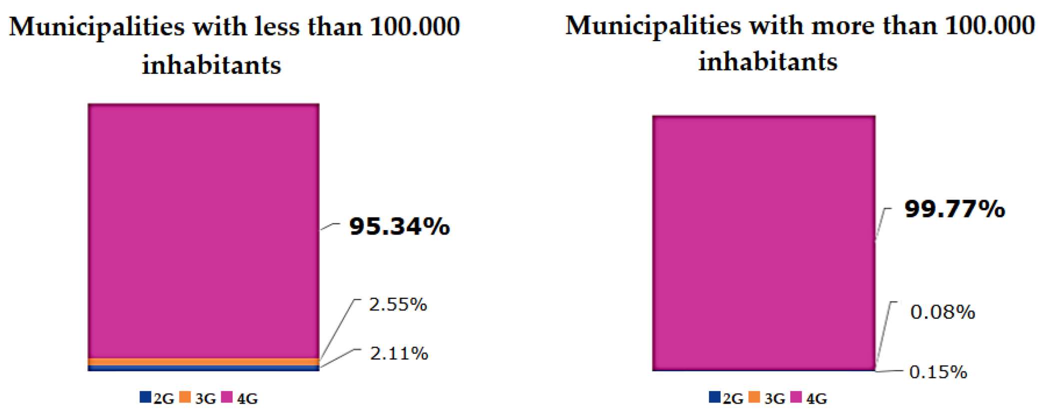

Figure 3. Coverage of 2G, 3G, and 4G technologies in Colombia. Source: [46].

This reality occurs despite the efforts made by MinTIC with the implementation of the Transition to New Technologies plan, and coverage expansion obligations undertaken by operators in the spectrum auction held in 2019 and defined in resolutions 3078 of 2019 and resolutions 330, 331, 332, and 333 of 2020. Regarding the 5G projection, MinTIC is betting on the 3500 MHz bands for the initial deployment. However, as of 2022, no spectrum auction has been held. Analog and digital TV broadcasting services currently occupy the 600 MHz band, but it is expected to be fully available in March 2029. As for the 26,000 MHz band, Colombia projects availability in 2027.

Relationship between IoT and 5G

IoT is becoming more popular and affordable every day, solving specific problems in different areas. Its mass deployment requires infrastructure that supports the connection of millions of devices, large bandwidths, and very low latencies [47]. These usage requirements cannot be efficiently met by 3G and 4G networks in a mass deployment scenario. Therefore, the advent of 5G is expected to meet these demands [48]. Certainly, 5G has great benefits in terms of transmission capacity, simultaneous connections, throughput, and security performance.

Figure 4 shows the 5G/IoT architecture composed of five layers known as sensor layer, network layer, communication layer, architecture layer, and application layer. The first layer collects physical magnitude data from the sensors. This information is then processed, transmitted, and shared with other devices connected to the network. Finally, application-specific actions are taken [49].

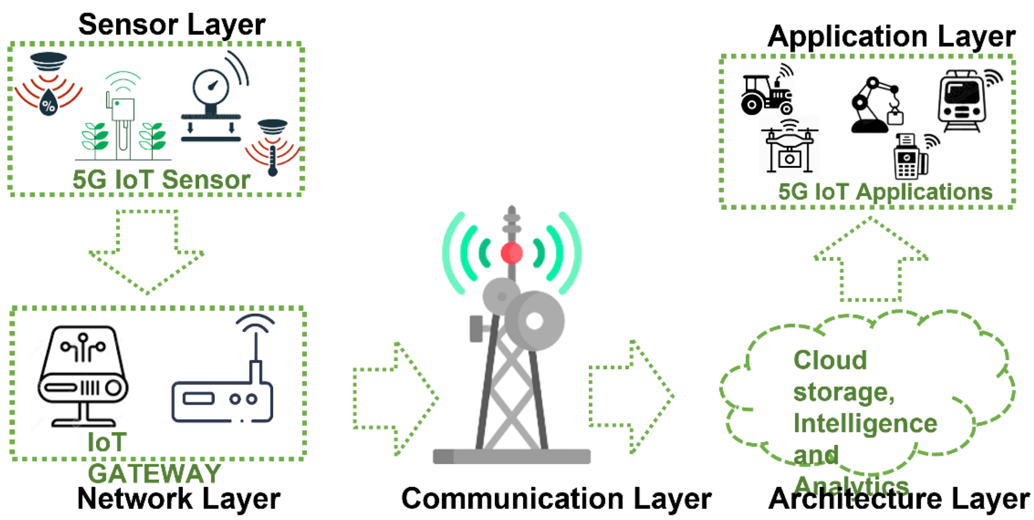

Figure 4. General 5G/IoT architecture. Source: [32].

7. Implementation of 5G Deployment in Colombia

In the case of Colombia, the MinTIC designed in December 2019 the 5G Plan that establishes the public policy guidelines and strategies that will serve as the basis for the deployment and massification of 5G in Colombia. This document contains the main challenges, strategies, and lines of action related to the radio spectrum, 5G pilots, the development of business models (applications and solutions) in 5G, digital security, and regulatory barriers to infrastructure deployment [50]. This process has been possible given the commitment of MinTIC, which through Resolution 638 of 2020 on 1 April 2020, initiated the granting of permits for the use of the radio spectrum to conduct pilot tests using 5G mobile technologies [51].

In compliance with the 5G Plan, on 9 March 2020, MinTIC published Resolution No. 467 which establishes the procedure for granting temporary permits for the use of the radio spectrum for technical tests [52]. Additionally, Resolution No. 638 of 1 April 2020 [53] opened the process of assigning permits for the use of the radio electric spectrum to carry out pilot tests using 5G mobile technologies through Resolution No. 722 of 30 April 2020 [54]. MinTIC granted permits to conduct pilot tests in the 3500 MHz frequency nationwide. The operators that were selected to carry out such tests in the cities of Bogotá, Bucaramanga, Cali, Medellín, and Tolú [55] are listed in **Table 3**.

Table 3. Operators assigned for 5G pilot in Colombia.

No.	Operator	Frequency Bands
1	Colombia Telecomunicaciones S.A E.S.P	3500 MHz–3600 MHz
2	Comunicación Celular S.A Comcel S.A	3500 MHz–3600 MHz
3	Empresa de Telecomunicaciones de Bógota S.A E.S.P	3500 MHz–3600 MHz
4	ITICS S.A.S	3500 MHz–3600 MHz
5	Xiris Investment Group SAS	3300 MHz–3400 MHz

Frequency Bands Identified in the 5G Deployment in Colombia

MinTIC, in harmony with the recommendations of the 2019 World Radiocommunication Conference, made available a set of frequencies enabled for the provision of 5G. The selection of these was based on the technical and commercial requirements demanded by 5G, as well as the interests of the nation. This section presents the current status of the aspiring frequency bands for 5G deployment in Colombia developed by the National Spectrum Agency (ANE) [50] (see **Table 4**).

Table 4. Candidate frequency bands for 5G deployment in Colombia.

Frequency bands		Advantages	Disadvantages
Low band (frequencies below 1 GHz)	600 MHz band (614–698 MHz)	Lower propagation losses and, therefore, requires fewer base stations (BSs) to provide coverage	Lower available bandwidth compared to the rest of the bands
	700 MHz band (698–806 MHz)		
Medium bands (frequencies in the range of 1 to 6 GHz)	3.4 GHz band (3.3–3.4 GHz)	Spectrum harmonized with most countries in the world	High occupancy of the radio spectrum
	3.5 GHz band (3.4–3.6 GHz)		
	3.6 GHz band (3.6–3.7 GHz)		
High band (frequencies higher than 6 GHz)	Item A (24.25–27.5 GHz)	High amounts of radio spectrum are available for critical applications requiring low latency	High radio signal losses require a greater amount of BS to provide coverage
	Banda de 28 GHz (26.5–29.5 GHz)		
	Item B (31.8–33.4 GHz)		

Frequency bands	Advantages	Disadvantages
Item C (37–40.5 GHz)		
Item K (71–76 GHz)		
Item L (81–86 GHz)		

[45]

region for ailability of technical parameters for frequenc rd bands, or other necessary technical measures to ensure interference-free operation of services operating in adjacency. The studies involve frequency blocks of 600 MHz, 900 MHz, and 2.3 GHz. Once these analyses have been completed, these parameters must be defined.

References

1. Spedding, R.C. Ecología de los Sistemas Agrícolas; H. Blume Ediciones: Madrid, Spain, 1979.
2. Ahmed, T.A.; El Gohary, F.; Tzanakakis, A.V.; Angelakis, N.A. Egyptian and Greek Water Cultures and Hydro-Technologies in Ancient Times. Sustainability 2020, 12, 9760.
3. Dayioğlu, A.M.; Turker, U. Digital Transformation for Sustainable Future-Agriculture 4.0: A review. J. Agric. Sci. 2021, 27, 373–399.
4. Said Mohamed, E.; Belal, A.A.; Kotb Abd-Elmabod, S.; El-Shirbeny, M.A.; Gad, A.; Zahran, B.M. Smart farming for improving agricultural management. Egypt. J. Remote Sens. Space Sci. 2021, 24, 971–981.
5. Gebbers, R.; Adamchuk, I.V. Precision agriculture and food security. Science 2010, 327, 828–831.
6. Mondal, P.; Basu, M. Adoption of precision agriculture technologies in India and in some developing countries: Scope, present status and strategies. Prog. Nat. Sci. 2009, 19, 659–666.
7. Núñez, V.J.M.; Vargas, L.V.; Quezada, M.Y.L. Implementation of a participatory methodology based on STEAM for the transfer of ICT knowledge and creation of Agtech spaces for the co-design of solutions that contribute to the development of small and medium agricultural producers in Colombia, Panama and China. In Proceedings of the 2020 IEEE World Conference on Engineering Education (EDUNINE), Bogota, Colombia, 15–18 March 2020; pp. 1–6.
8. Nyaga, J.M.; Onyango, C.M.; Wetterlind, J.; Söderström, M. Precision agriculture research in sub-Saharan Africa countries: A systematic map. Precis. Agric. 2021, 4, 22.
9. Faid, A.; Sadik, M.; Sabir, E. An Agile AI and IoT-Augmented Smart Farming: A Cost-Effective Cognitive Weather Station. Agriculture 2022, 12, 35.
10. Thorat, A.; Kumari, S.; Valakunde, D.N. An IoT based smart solution for leaf disease detection. In Proceedings of the 2017 International Conference on Big Data, IoT and Data Science (BID), Pune, India, 20–22 December 2017; pp. 193–198.
11. Karim, F.; Karim, F. Monitoring system using web of things in precision agriculture. Procedia Comput. Sci. 2017, 110, 402–409.
12. Navulur, S.; Prasad, G.M. Agricultural management through wireless sensors and internet of things. Int. J. Electr. Comput. Eng. 2017, 7, 3492.
13. Alonso, S.R.; Sittón-Candanedo, I.; García, Ó.; Prieto, J.; Rodríguez-González, S. An intelligent Edge-IoT platform for monitoring livestock and crops in a dairy farming scenario. Ad Hoc Netw. 2020, 98, 102047.
14. Islam, N.; Rashid, M.M.; Pasandideh, F.; Ray, B.; Moore, S.; Kadel, R. A Review of Applications and Communication Technologies for Internet of Things (IoT) and Unmanned Aerial Vehicle (UAV) Based Sustainable Smart Farming. Sustainability 2021, 13, 1821.
15. Ramirez-Morales, I.; Mazon-Olivo, B.; Pan, A. Capítulo 1: Ciencia de datos en el sector agropecuario. In Análisis de Datos Agropecuarios; Universidad Técnica de Machala: Machala, Ecuador, 2018; pp. 12–44.
16. Catelani, M.; Ciani, L.; Bartolini, A.; Del Rio, C.; Guidi, G.; Patrizi, G. Reliability Analysis of Wireless Sensor Network for Smart Farming Applications. Sensors 2021, 21, 7683.
17. Naciones Unidas. Población|Naciones Unidas. Naciones Unidas. 2022. Available online: https://www.un.org/es/global-issues/population (accessed on 8 August 2022).

18. Bacco, M.; Barsocchi, P.; Ferro, E.; Gotta, A.; Ruggeri, M. The Digitisation of Agriculture: A Survey of Research Activities on Smart Farming. Array 2019, 3–4, 100009.
19. United Nations. “El Papel de la Gobernanza Electrónica en la Reducción de la Brecha Digital|Naciones Unidas,” United Nations. Available online: https://www.un.org/es/chronicle/article/el-papel-de-la-gobernanza-electronica-en-la-reduccion-de-la-brecha-digital (accessed on 8 August 2022).
20. O’Shaughnessy, S.A.; Kim, M.; Lee, S.; Kim, Y.; Kim, H.; Shekailo, J. Towards smart farming solutions in the U.S. and South Korea: A comparison of the current status. Geogr. Sustain. 2021, 2, 312–327.
21. World Bank. Water in Agriculture. Available online: https://www.bancomundial.org/es/topic/water-in-agriculture (accessed on 8 August 2022).
22. Ghutke, P.; Agrawal, R. The utilization of IoT and remote sensor organizations and their application in agriculture for the improvement of yield productivity in India. In Proceedings of the 2021 2nd Global Conference for Advancement in Technology (GCAT), Bangalore, India, 1–3 October 2021; pp. 1–6.
23. Balasubramaniyan, M.; Navaneethan, C. Applications of Internet of Things for smart farming—A survey. Mater. Today Proc. 2021, 47, 18–24.
24. Tang, Y.; Dananjayan, S.; Hou, C.; Guo, Q.; Luo, S.; He, Y. A survey on the 5G network and its impact on agriculture: Challenges and opportunities. Comput. Electron. Agric. 2021, 180, 105895.
25. Navarro-Ortiz, J.; Romero-Diaz, P.; Sendra, S.; Ameigeiras, P.; Ramos-Munoz, J.J.; Lopez-Soler, J.M. A Survey on 5G Usage Scenarios and Traffic Models. IEEE Commun. Surv. Tutor. 2020, 22, 905–929.
26. UIT-R. Concepción de las IMT–Marco y objetivos generales del futuro desarrollo de las IMT para 2020 y en adelante; UIT-R: Geneva, Switzerland, 2015; p. 22.
27. GSMA. 5G Spectrum, GSMA Public Policy Position. 2019. Available online: https://www.gsma.com/latinamerica/wp-content/uploads/2019/03/5G-Spectrum-Positions-InfoG.pdf (accessed on 8 August 2022).
28. Constaín, S.; Gaviria, I.A.M. Plan 5G Colombia El Futuro Digital es de Todos; Ministerio de Tecnologías de la Información y las Comunicaciones: Bogotá, Colombia, 2019; p. 93.
29. Mekuria, F.; Mfupe, L. Spectrum Sharing for Unlicensed 5G Networks. In Proceedings of the 2019 IEEE Wireless Communications and Networking Conference (WCNC), Marrakech, Morocco, 15–18 April 2019; pp. 1–5.
30. ANE. Plan Maestro de Gestion de Espectro a 5 años. 2022. Available online: https://www.ane.gov.co/Sliders/archivos/Cargas%20Nuevas/Plan%20Maestro%20de%20Gestion%20de%20Espectro%20a%205%20a% (accessed on 8 August 2022).
31. MinICT. Mintic Expects to Have a 5G Auction Before Government Ends-Mintic Expects to Have a 5G Auction Before Government Ends. MINTIC Colombia. Available online: http://www.mintic.gov.co/portal/715/w3-article-161584.html (accessed on 8 August 2022).
32. MinICT. Spectrum Auction Remains: Sylvia Constain, ICT Minister-MINTIC Colombia. Available online: http://www.mintic.gov.co/portal/715/w3-article-118136.html (accessed on 8 August 2022).
33. MinICT. Normogram of the Ministry of Information and Communications Technologies . Available online: https://normograma.mintic.gov.co/mintic/docs/resolucion_mintic_3078_2019.htm (accessed on 8 August 2022).
34. MinICT. Normogram of the Ministry of Information and Communications Technologies . Available online: https://normograma.mintic.gov.co/mintic/docs/resolucion_mintic_3121_2019.htm (accessed on 8 August 2022).
35. MinTIC. Resolution 1322-Preliminary Analysis of the Objective Selection Process for the Allocation of Spectrum Use Permits in IMT Bands. 2020. Available online: https://mintic.gov.co/portal/715/articles-146624_resolucion_1322_20200727.pdf (accessed on 8 August 2022).
36. Qualcomm. Global Update on 5G Spectrum. 2019. Available online: https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/spectrum-for-4g-and-5g.pdf (accessed on 8 August 2022).
37. MinICT. Resolution 325-Granting a Permit for the Use of the Radio Spectrum to Comunicación Celular S.A. COMCEL S.A. con NIT 800.153.993—7. Available online:

https://www.mintic.gov.co/micrositios/asignacion_espectro-imt/742/articles-172495_Resolucion_No__325.pdf (accessed on 8 August 2022).

38. MinICT. Resolution 326-Granting a Permit for the Use of the Radio Spectrum to Comunicación Celular S.A. COMCEL S.A. con NIT 800.153.993—7. Available online: https://www.mintic.gov.co/micrositios/asignacion_espectro-imt/742/articles-172496_Resolucion_No__326.pdf (accessed on 8 August 2022).
39. MinICT. Resolution 327-Granting a Permit for the Use of the Radio Spectrum to Comunicación Celular S.A. COMCEL S.A. S.A. con NIT 800.153.993—7. Available online: https://www.mintic.gov.co/micrositios/asignacion_espectro-imt/742/articles-172497_Resolucion_No__327.pdf (accessed on 8 August 2022).
40. MinICT. Resolution 328-Granting a Permit for the Use of the Radio Spectrum to Comunicación PARTNERS TELECOM COLOMBIA S.A.S.354.361—1. Available online: https://www.mintic.gov.co/micrositios/asignacion_espectro-imt/742/articles-172499_Resolucion_No__328.pdf (accessed on 8 August 2022).
41. MinICT. Resolution 330-Granting a Permit for the Use of the Radio Spectrum to PARTNERS TELECOM COLOMBIA S.A.S.354.361—1. Available online: https://www.mintic.gov.co/micrositios/asignacion_espectro-imt/742/articles-172501_recurso_1.pdf (accessed on 8 August 2022).
42. MinICT. Resolution 331-Granting a Permit for the Use of the Radio Spectrum to a COMUNICACIÓN CELULAR S.A. COMCEL S.A. con NIT 800.153.993—7. Available online: https://www.mintic.gov.co/micrositios/asignacion_espectro-imt/742/articles-172502_recurso_1.pdf (accessed on 8 August 2022).
43. MinICT. Resolution 332-Granting a Permit for the Use of the Radio Spectrum to co 8 COLOMBIA MÓVIL S.A. ESP con NIT 830.114.921—1. Available online: https://www.mintic.gov.co/micrositios/asignacion_espectro-imt/742/articles-172503_recurso_1.pdf (accessed on 8 August 2022).
44. MinICT. Resolution 333-Granting a Permit for the Use of the Radio Spectrum to COLOMBIA MÓVIL S.A. ESP con NIT 830.114.921—1. Available online: https://www.mintic.gov.co/micrositios/asignacion_espectro-imt/742/articles-172504_recurso_1.pdf (accessed on 8 August 2022).
45. ANE. Public Consultation on Available Bands for the Future Development of IMT in Colombia. 2020. Available online: https://www.ane.gov.co/Documentos%20compartidos/ArchivosDescargables/noticias/Consulta%20p%C3%BAblica%20sobre%20las%20 (accessed on 8 August 2022).
46. MinICT. Documento Soporte y Consulta Pública. Desarrollo 5G en Colombia. Available online: https://www.mintic.gov.co/portal/715/articles-236811_documento_soporte_consulta_publica_desarrollo_5g_colombia.pdf (accessed on 8 August 2022).
47. Khurpade, M.J.; Rao, D.; Sanghavi, P.D. A Survey on IOT and 5G Network. In Proceedings of the 2018 International Conference on Smart City and Emerging Technology (ICSCET), Mumbai, India, 5 January 2018; pp. 1–3.
48. Painuly, S.; Sharma, S.; Matta, P. Future Trends and Challenges in Next Generation Smart Application of 5G-IoT. In Proceedings of the 2021 5th International Conference on Computing Methodologies and Communication (ICCMC), Erode, India, 8–10 April 2021; pp. 354–357.
49. Chettri, L.; Bera, R. A Comprehensive Survey on Internet of Things (IoT) Toward 5G Wireless Systems. IEEE Internet of Things J. 2020, 7, 8879484.
50. MinICT. Ministry of Information and Communications Technology-Adoption of 5G technology in Colombia. 2020. Available online: https://mintic.gov.co/micrositios/plan_5g//764/articles-162230_recurso_1.pdf (accessed on 8 August 2022).
51. MinICT. Informe de Asignación–Espectro Para Uso de Pruebas Tecnicas 5G; Ministerio de las tecnologías de la Información y las Comunicaciones MINTIC: Bogotá, Colombia, 2020. Available online: http://www.mintic.gov.co/portal/715/w3-article-180029.html (accessed on 8 August 2022).
52. MinICT. Resolution 467 of 1 July 2020; Ministry of Information and Communications Technology-MinICT: Bogotá, Colombia, 2020. Available online: https://normograma.mintic.gov.co/mintic/docs/resolucion_icanh_0467_2020.htm (accessed on 8 August 2022).

53. MinICT. Resolution 000638 of 1 April 2020; Ministry of Information and Communications Technology - MinICT: Bogotá, Colombia, 2020; pp. 1–6. Available online: https://micrositios.mintic.gov.co/plan_5g/pdf/resolucion_638.pdf (accessed on 8 August 2022).
54. MinICT. Resolución Numero-00722 DE 30 de Abril de 2020. 2020. Available online: https://www.mintic.gov.co/portal/604/articles-135751_resolucion.pdf (accessed on 8 August 2022).
55. MinICT. 'El 5G Será Una Herramienta de Sofisticación Para el Desarrollo Industrial Colombiano': Walid David, Viceministro de Conectividad del MinTIC. MINTIC Colombia. Available online: http://www.mintic.gov.co/portal/715/w3-article-180029.html (accessed on 8 August 2022).