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The Sustainability, Traceability and Succession of the Quebec Agri-Food Sector Depends on an Acceleration of Digitization

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The Sustainability, Traceability and Succession of the Quebec Agri-Food Sector Depends on an Acceleration of Digitization

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Abstract

To promote local purchasing and production and to strengthen supply chains while accelerating the green shift in Quebec's agri-food sector, digitization is imperative. Because only the digitization of food production, processing and distribution will generate the data needed to achieve these objectives. Digitization will also make it possible to "trace" the food we produce and thus validate its quality and origin, requirements that have become essential for both domestic and international markets.

Thanks to this data on Quebec's agri-food ecosystem, we will be able to make our supply chains more resilient as well as measure and ultimately reduce the ecological footprint of agri-food chains. To make the digitization of these sectors a real priority, certain conditions must be met beforehand: equip all agricultural regions with high-speed Internet connections, establish an inventory for each sector, quickly create a monitoring center to benefit from foreign experiences and mobilize, for several years, a team dedicated fulfill this project. These are certainly demanding conditions, but they are also very structuring for the Quebec economy.

Keywords: Traceability, Digitization, Agri-food, Data, Sustainability, Blockchain

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Introduction

Quebec, like other societies around the world, has entered the fourth Industrial Revolution: the digital revolution. The main characteristic of the new digital technologies is that they are intertwined and come on top of each other to establish permanent networks of communication and interaction between people, objects, and machines through the digitization (or digitalization) of all business processes. The customer can now place an order for a product according to their needs directly over the Internet; payment and transfer of funds are made instantly over the Internet; suppliers will produce and deliver the product very quickly. This integration of sales, production, quality control, inventory management, distribution and payment processes shakes up old business models and radically transforms the sources of value creation while shifting profit margins between the players in a sector or market. At the same time, billions of pieces of data are simultaneously emerging as the key to defining winning industrial strategies and optimally managing the production and distribution operations of goods, including food.

> *The digital revolution and the rise of platforms and aggregators are changing the distribution of all products, including food products.*

Understanding the multiple implications of this digital revolution affecting all sectors of the economy is an essential prerequisite for assessing how the digital revolution and the rise of platforms and aggregators are changing the distribution of all products, including food products. The first section of this document presents this new industrial dynamic that drives the urgency of digitizing Quebec's agri-food sector.

The second section deals with agri-food and digital technology and covers: precision agriculture, digital agriculture, sustainable food, and the optimization of agri-food supply chains. Agriculture has always benefited from great technological discoveries; more than fifty years ago, what we call today precision agriculture was born, which aims to adopt the right cultivation practice, on the right soil, at the right time and with the right intensity. This precision agriculture is the cornerstone of digital agriculture. Precision comes from the multiple sensors installed on farm equipment, the many GPS, lasers and drones that read the soil on farms, the sophisticated seeding, spraying and harvesting tools used in the fields, and the intelligent systems installed to feed, milk and monitor animals in barns and outdoors. All this equipment is connected to Internet networks and provides farmers and their suppliers with the data to better manage their operations.

Digital farming is a broader and more encompassing concept than precision farming because it involves the farm and its ecosystem of suppliers, distributors and other stakeholders including regulators, governments, customers, and the public. It is therefore only natural that digitizing the ecosystem of an agri-food chain should lead to facilitating sustainable food while at the same time being a very powerful lever for optimizing supply chains.

This digital revolution is therefore urgently needed around the world because these technologies can help companies address the many challenges associated with food, such as increasing the supply of food to populations, food safety and traceability, the ecological transition of the agri-food sector, and the need to make supply chains more effective, resilient and efficient for the benefit of all. Objectives embraced by MAPAQ and the Quebec government.

The digitization of the agri-food sector is already producing astronomical amounts of data. Because this data must be of high quality and verifiable, while being secured to protect the privacy and competitive advantages of producers and distributors, blockchain technology is increasingly emerging as the most appropriate technological architecture to manage these data flows. This technology is presented in this text, and references to numerous projects underway around the world are provided.

> *Digital is not a sector in itself, but a transversal component to all sectors of the economy.*

The third section discusses the challenges and obstacles to digitization in the Quebec agri-food sector, and highlights the technical, organizational, and cultural dimensions of these difficulties. Among these obstacles, the most important remains the connectivity of Quebec's agricultural territories: nearly 70% of regions that are described as "well served" actually have connections at speeds below the minimum threshold established by the Canadian Radio-television and Telecommunications Commission (CRTC). Another major challenge is to convince the agri-food sector to accelerate its digital shift while identifying the right public policies to support it in this process and offer effective financial incentives.

The conclusion of this document comes back forcefully on the need to win the data war in a digitized world and offers a summary of the arguments that motivate the urgency of digitizing Quebec's main agri-food sectors. Digital is not a sector in itself, but a transversal component to all sectors of the economy. It is an indispensable and unavoidable lever for achieving the strategic objectives envisioned by the MAPAQ. The conclusion also sets out five recommendations to promote the digitization of Quebec's agri-food sector.

1. The Digital Revolution

1.1. A New Industrial Dynamic

The fourth Industrial Revolution (the digital revolution) is believed to have initiated in Germany around 2013 (Petrillo et al., 2018) and has rapidly spread to other parts of the world. The first Industrial Revolution dates back to the end of the 18th century and allowed the mechanization of production thanks to the invention of the water and steam engine, as well as machine tools; it was followed by the second revolution which developed thanks to the electrification of factories; it was then that mass production became widely accepted, inspired by the model of the Ford factories. It was not until the end of the last century and the beginning of the 21st century that the third revolution in manufacturing industry appeared, characterized by a wave of automation and robotization that was accompanied by a greater penetration of electronics and information technology in all the goods and services sectors of the economy. And barely twenty years later, Industry 4.0 and the digital revolution were born, triggering a tsunami of changes in just a few years, this time not only in manufacturing, but also in the distribution of goods and services across all industries and in all types of private and public organizations (Greenman, 2019).

The main characteristic of the new technologies is that they overlap to establish permanent networks of communication and interaction between people, objects, and machines through the digitization (or digitization) of all business processes. Customers can now order a product or service according to their needs directly through the Internet; payment and transfer of funds are made instantly through the Internet; this information is instantly transmitted to suppliers who will produce and deliver the product and service very quickly. This integration of sales, production, quality control, inventory management, distribution and payment processes shakes up old business models and radically transforms the sources of value creation while shifting profit margins between the players in a sector or market. Let's take a closer look at this.

Before the appearance and generalization of the Internet, any industrial sector was composed of three blocks: producers (manufacturers, food or service companies, craftsmen, and farmers), distributors (wholesalers and retailers), and customers (individuals and companies). In this pre-digital world, the information costs incurred by producers to communicate with suppliers and customers, on the one hand, and the costs of distribution, exchange and transactions between the various players, on the other hand, were so high that to dominate an industry it was essential either to control the supplier market by being vertically integrated, or to govern the distributor market by having built a strong horizontal presence in a region or market. For example, if the regional weekly newspaper had built a dominant position as the primary medium for delivering local and regional news to all residents of the region, it would be able to capture advertising revenues from regional suppliers. It had the lowest communication costs and this advantage allowed it to dominate the news market. While it was able to compete, even then, the industrial dynamics of the pre-digital world were preserved.

In a digital world, the industrial logic is radically modified because with the generalization of the Internet, the marginal cost to disseminate additional information to a very large number of customers is almost nil, just as the marginal cost to execute a transaction is almost nil. Of course, building a business based on intensive use of the Internet represents significant fixed costs and takes time, but once the software and network infrastructures have been put in place, the marginal cost of information, transaction and distribution via the Internet tends towards zero. In addition, there are now platforms and applications available to start a new business on the Internet at costs radically lower than those prevailing in a pre-digital world (and in the early digital world). Shopify, a Canadian company, offers exactly this type of service to small and medium-sized businesses by offering monthly packages from the simplest to the most sophisticated (shopify.com). It is this change in cost structure that is causing a new business paradigm and setting up a new industrial dynamic that is giving rise to and growing new business models. Among these new models, it is useful to recognize the most relevant ones.

Ben Thompson from Stratechery (2017) presented these different models in a very pedagogical way and especially explained how these companies succeed in building "moats" (Moat Map) that protect them from their competitors and eventually allow them to become dominant, thus validating the winner takes all thesis.

> *In a digital world, the industrial logic is radically modified because with the generalization of the Internet, the marginal cost of disseminating additional information to a very large number of customers is almost nil, just as the marginal cost of executing a transaction is almost nil.*

He uses two indicators: the level of supplier differentiation and the degree of outsourcing of network effects. Based on this representation, Thompson distinguishes two company archetypes: aggregators and platforms.

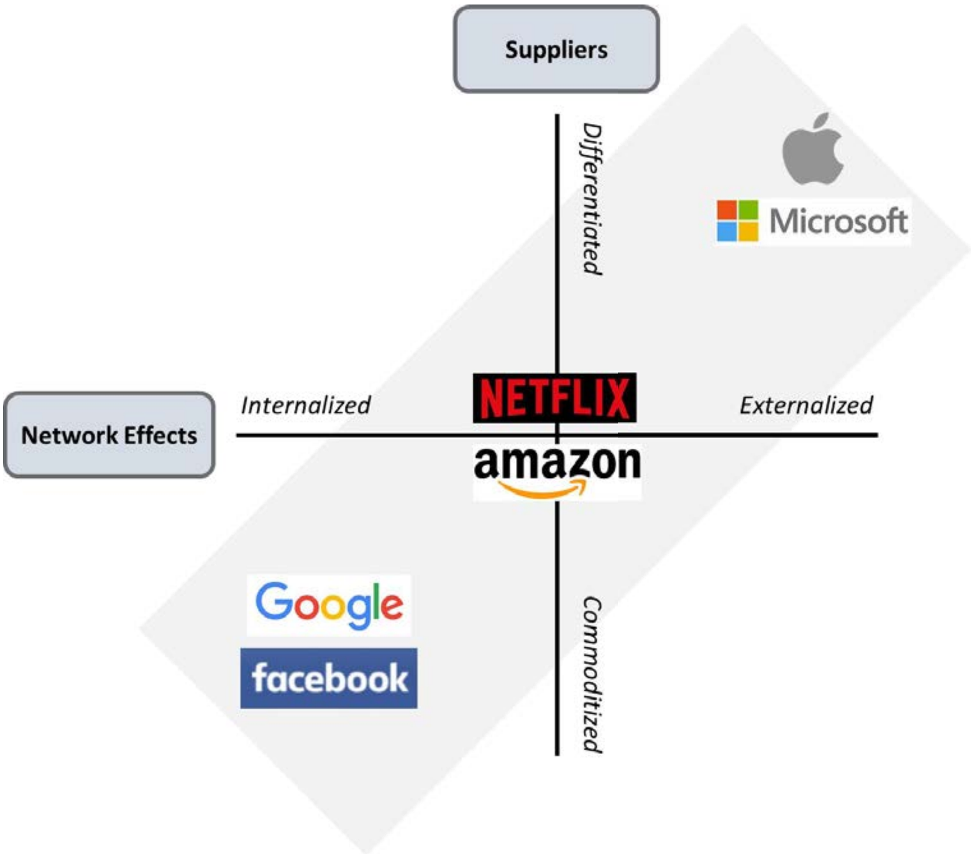

Figure 1 – Representation of the "moat" concept (Moat Map, Thompson, 2017)

1.1.1. Aggregator Business Model

For Thompson (2017), the two largest aggregators of customers and/or data are Facebook and Google. The first has managed to aggregate more than 2.4 billion members who exchange a lot of information of all kinds, while the second is connected to more than 2 billion devices with billions of individuals and businesses, managing an almost unlimited amount of data of all kinds. In both cases, these companies benefit from two extremely protective effects: virtuous network effects that are totally internalized, and the effects of independence and indifference of their suppliers, which provide them with the most effective wall of protection against competition. Facebook's ability to charge for advertising space increases as the number of members increases on its network; however, the more members there are, the more attractive the network becomes for advertisers and also for current and future members because they can reach more friends; this is the logic of the network effect creating a virtuous circle.

> *[...] the more members there are, the more attractive the network becomes for advertisers and also for current and future members, because they can reach more friends; this is the logic of the network effect creating a virtuous circle.*

Moreover, as with Facebook, the providers of information, photographs, and ultimately any content present on the site are in fact the users (members) of the network themselves. Facebook is completely independent and indifferent to its providers: it is a pure aggregator! Google is also an aggregator, but with a few small nuances; as a network on the Internet, Google also benefits from positive network effects, because the more users there are, the more it is able to demand more from its advertisers and the more information and data will be numerous and growing. However, Google would be slightly less independent of its suppliers because it uses certain incumbent suppliers with whom it can partially share its advertising revenues. However, Google remains the dominant or even overwhelming search engine – nearly 93% market share as of October 2020 – and reaps profits thanks to its "walls of protection" provided by network effects (Statcounter GlobalStats, 2020).

1.1.2. Platform Business Model

At the other end of the spectrum, the network effect and vendor independence, Thompson identifies platforms and recognizes two major players: Apple and Microsoft. Indeed, in both cases, their strength lies in this fabulous ecosystem of differentiated vendors who day after day deliver new applications that are always better than the latest and add multiple features to Apple and Microsoft devices and software, ensuring the dominance of their products in their markets. What's more, neither Microsoft nor Apple benefits from network effects per se (unless you think of Apple stores as a network). In fact, pure platforms have built their wall of protection precisely because of their ecosystem of vendors that provide them with the ability to create high-value-added tools and applications that help them build their brand. This hasn't stopped Microsoft Office from dominating its market, but it wasn't through network effects. Similarly, Apple has not only been able to dominate markets, but sometimes even transform them through its products, such as the smartphone. Before the iPhone, consumers wanting a cell phone chose and dealt primarily with the telephone operator and its package offer, the model or brand of the device were secondary. This hierarchy was reversed with the release of the iPhone and the appearance on the market of competing smartphones: consumers wanting to get the device (iPhone) before the service (the phone package) naturally turned to certain operators offering the coveted device(s) on an exclusive basis (Dissanayake and Amarasuriya, 2015; Sandler, 2019). Today, a glance at the telephone operators' advertisements reveals this almost total reversal of dependence between the latter and the device manufacturers, and the operators are obliged to offer certain flagship products or risk depriving themselves or even losing many customers (Lescop and Lescop, 2013). This reversal of the situation is the result of the deployment of aggressive marketing, on the one hand, and the implementation of predatory and anti-competitive behavior on the other (Agence France-Presse, 2020).

1.1.3. Hybrid Business Model: "Aggregator Platforms"

Finally, according to Thompson, there is a hybrid model where we find companies such as Amazon and Netflix, which are in fact aggregator platforms. On the one hand, they benefit from positive and partially internalized network effects; the more buyers there are on Amazon, the more Amazon can negotiate lower costs from its suppliers, and the more its fixed costs can be amortized over a larger number of customers; on the other hand, their suppliers are partially differentiated although they do not have much power on Amazon, because Amazon benefits from network effects large enough to be fairly independent of its suppliers. Indeed, aggregator platforms are networks for more than one reason: at least a network of suppliers and a network of customers. In fact, it is a whole ecosystem of partners that gravitates around Amazon and makes it its strength. Shopify has also developed a similar partner ecosystem and is trying to position itself as a competitor of Amazon (Thomson, 2019; Strain, 2020).

A closer look at Amazon's business model allows us to better understand the fundamental difference between the pre-digital industrial logic and that resulting from the digital world.

In its early days, Amazon bought books at wholesale prices from its suppliers and resold them at retail prices to its customers, following the logic of the pre-digital world: Amazon was a simple intermediary that certainly benefited from lower information and transaction costs thanks to the Internet and acted as a platform by facilitating relations between third parties. Over time, the number of available products increased, and Amazon became increasingly efficient while increasing the number of its distribution and logistics centers across the United States and then around the world.

Today, Amazon's logistics capabilities are so large and efficient that Amazon has become a provider of web-based goods distribution services without customers really being able to distinguish between wholesalers who sell their products to Amazon (who then resell them at a distributor's margin), and suppliers who use Amazon's logistics services and capabilities (who then receive revenue for the logistics services they provide).

> *Amazon recently acquired Wholefoods not to acquire a supplier, but rather to acquire a customer, and thus control the cold chain and components of food distribution with the goal of becoming a platform of choice for all grocers. Amazon becomes a platform of platforms!*

Customers who buy on Amazon experience the exact same experience in both cases. Because the experience is excellent, more and more providers want to use Amazon, which benefits from a network effect characteristic of the digital world. Amazon created Amazon Prime in 2007 allowing its best customers to participate in a loyalty program offering them free and fast delivery, discounts on purchases of movies or goods in its stores such as Wholefoods. According to the Consumer Intelligence Research Partnerships, today more than 65% of its customers have subscribed to the Amazon Prime offer, representing more than 126 million consumers (figures from the end of the third quarter of 2020, just in the United States).

In less than 20 years, the number of Amazon's logistics centers has grown from a few to more than 100, while Walmart, which began operations more than 50 years ago, has only about 20 distribution and logistics centers. Walmart makes up for this delay with its 4500 points of sale, but Amazon's weapon of combat is its logistics, which supports the customer experience on the Internet. Amazon has become no longer a simple aggregator, but a multifaceted distribution platform for consumers (business to consumer, B2C), but also for companies (business to business, B2B) (Thompson, 2017). That's not all: Amazon has also become a platform offering cloud computing services (Amazon Web Services, AWS) to a growing number of startups, small and medium companies, as well as some of its competitors. It is a key player in retail as well as wholesale on the Internet! Finally, Amazon recently acquired Wholefoods not to acquire a supplier, but rather a customer, and thus control the cold chain and components of food distribution with the goal of becoming a platform of choice for all grocers. Amazon becomes a platform of platforms (Montet, 2020)! Thomson also calls them "super-aggregators" (Thomson, 2017; Thomson, 2020; Wu, 2020).

The digital revolution is not only shaking up the distribution sector; the manufacturing and agri-food sectors are also directly affected by these new technologies. The digitization of processes creates networks of interactions between objects, machines and robots because they use increasingly sophisticated sound and image sensors and continuously generate data on the quantity produced, production deadlines and quality, wear and tear on machine tools, the level of input inventories, soil quality, the productivity of agricultural equipment, goods in production and finished goods, etc. The digital revolution is not only shaking up the distribution sector, the manufacturing and agri-food sectors are also directly affected by these new technologies. This data becomes a source of information to better manage processes and optimize the use of resources. This data also feeds intelligent algorithms that contribute to the continuous improvement of processes, carried out automatically. These systems, which combine the physical and digital worlds, enable the integration of information technology and data processing system with the mechanical and electronic components of production equipment and processes.

1.2. An Example of Digitization in the Agri-Food Industry in Quebec: Patates Dolbec

A good example of the use of interoperability between the physical and digital worlds is the digitization and robotization of a potato harvesting, grading, packaging, and distribution plant (see youtu.be/7Yd4_kNtU_8). When the potatoes arrive at the Dolbec plant in Saint-Ubalde, they are stored according to the field where they were harvested and, immediately, characteristics are associated with them such as the variety of potatoes, the personnel who harvested them, the date and time of their harvest, etc., which from the outset generates a lot of data. From there, they are moved by conveyors to washing machines and then passed to an optical sorter to determine their shape, size, color, imperfections, or diseases. They are then placed in bins corresponding to the sorting carried out. These bins are weighed and sent to a refrigerated warehouse where they are stored for a few hours or a few days, waiting to be prepared to fill customer orders.

> *Since the digitization of its plant, Patates Dolbec delivers more potatoes than ever before with the same number of workers, and the company has managed to substantially reduce its delivery times. This allows the company to offer its customers fresh products year-round.*

Traders can order the quantity and type of potatoes they wish to purchase directly over the Internet. A planning exercise follows to schedule the bagging: robots/shuttles bring the bins from the cold-storage warehouse to the robotic packers, who then place the potatoes in bags bearing the company's brand and reference to the fields harvested and other traceability data (e.g., lot, date, time). The company's inventories are recorded automatically and in real time in an Enterprise Resource Planning (ERP) system.

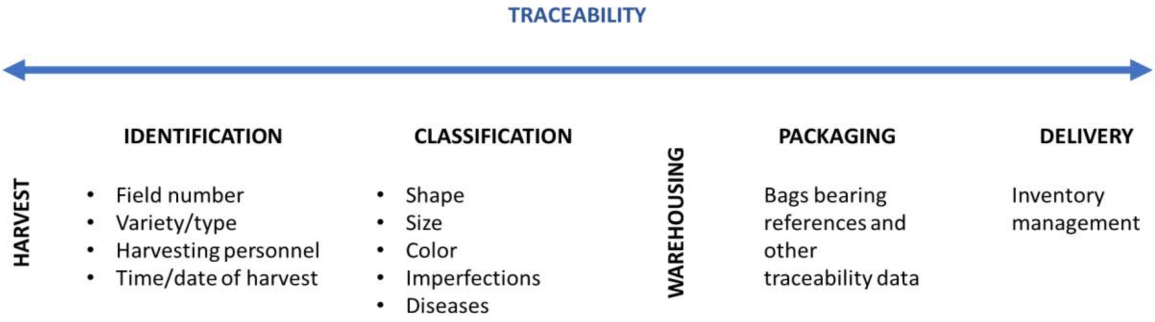

Figure 2 – Patates Dolbec traceability chain: from the soil to the grocery shelves

At each stage of the harvesting and production process, from washing to grading, packaging and delivery, all stages of the process generate data that is read by sensors, RFID (Radio Frequency Identification, a technology for automatic detection and identification by radio frequency) identifiers, actuators, digital photographic images and various software and wireless solutions. From the ground to the table, everything is fully digitized and automated, allowing for intelligent management of the company. Machines, systems, and products exchange information with each other and with the outside world via the Internet. Since the digitization of its plant, Patates Dolbec delivers more potatoes than before, with more varieties, with the same number of workers, and the company has managed to substantially reduce its delivery times. It can thus offer its customers fresh products year-round.

The experience of potato traders and consumers is greatly improved. Thanks to the numerous data resulting from digitization, the traceability of the product from farm to table is complete and provides consumers with an unequalled level of transparency. Through a simple barcode, they can know the exact origin of the product they are consuming. What's more, the producer has complete control over the quality of his product and can, if necessary, recall a particular lot of potatoes, because he knows who bought what, when and from which lots the potatoes came.

There are many examples of agri-food and manufacturing companies that have already integrated traceability technologies into their business models (Petrillo et al., 2018; Poore et al., 2018).

1.3. Learning Algorithms and the Artificial Intelligence and Digital Industry

We are witnessing continuous advances in information technology in terms of the computing capacity of computers (quantum computing) and infrastructures (cloud computing), as well as in the physical, chemical, and biological sciences. However, the real revolution comes from the interaction of all these multiple discoveries with the arrival and spread of artificial intelligence and in particular deep learning, which allows algorithms to map, recognize or identify patterns and trends using large data sets. These "apprentices" are now able to recognize and perceive images and sounds in impressive ways because they have a greater memory and computational capacity that allows them to perform many tasks with much lower error rates than those recorded by human beings (Paredes, 2018; Sargeant, 2019). Such algorithms have been used in the medical field, for example for diagnostic development (Devarakonda and Tsou, 2014) and in imaging analysis (Pesapane et al., 2018; Imagia, 2020). It is thanks to all these techniques that the industry can now use autonomous vehicles and robots of all kinds, which are interconnected and perform many complex tasks in changing environments. Petrillo et al. (2018) explain well that the capture of this data makes it possible to transpose the many physical objects such as inputs, robots or products into numerical symbols that are then put in communication in a digital network where it is possible to make calculations, memorize and combine to translate this big data into information and management decisions. These authors identify five levels of functionalities of cyber-physical systems that we take the liberty of illustrating using the case of potatoes (NB: This is to exemplify and not to present facts verified in the factory). The following are the five levels of functionality:

- Level 1: **The intelligent connection**. The ability to acquire and manage data in real time thanks to intelligent sensors that transfer it to the right place in the system using specific pre-established communication protocols. For example, sensors on potato bins send a signal when the bin is full of potatoes and the system must command a robot to transport that bin to the right place in the warehouse, before bringing an empty bin in for refilling.
- Level 2: **Conversion of data into information**. The ability of the system to aggregate data and convert it into value-added information. For example, after washing and grading a certain number of potatoes, the robot that washes the potatoes identifies that an abnormally high number of potatoes are very small.
- Level 3: **Digital matching**. The ability to represent a very real world in the digital world. For example, the same system adds that this very high level of small potatoes is incompatible with an already very high inventory level of small potatoes in the warehouse.
- Level 4: **Cognition**. The ability to identify multiple scenarios and support a decision process. For example, the system, using data on recent deliveries to different customers and production and packaging data, establishes scenarios on the future evolution of inventories and the consequences on cost price and possible losses due to this abnormally high level of small potatoes.
- Level 5: **Configuration**. The system can comment on reality while using digital and virtual data and to propose corrective measures. For example, the system proposes,

taking into account the weather data of the current season in comparison with previous years, a revision of the classification of potato fields based on recent data indicating a smaller potato crop than before; the system also proposes a revision of the planning of potato harvest in the fields based on inventories and sales. The system, after testing the accuracy of the robot that washes and grades the potatoes, indicates that no grading defects were detected. Finally, the system also proposes a small potato price reduction program to restore inventories to optimal levels and provides an analysis of the financial implications of the proposed price reduction program. Finally, the system adds a concrete proposal to establish the list of customers to whom this price reduction proposal should be made, considering the objectives of developing new markets and retaining the most profitable customers.

In other words, modern societies are only at the beginning of a new era of discoveries and applications that will bring benefits and challenges in all fields such as agriculture and food, land and air transportation, education, finance, healthcare and medicine, commerce, energy, logistics, robotics, not to mention the ethical, moral and governance issues that these new developments will raise. The applications are also numerous, ranging from the recognition of characters, speech, human figures, to the manipulation and classification of photographs or images of all kinds, to the ability to diagnose a disease, a situation, a problem, etc.

> *[…] modern societies are only at the beginning of a new era of discoveries and applications that will bring a tsunami of benefits and challenges in all areas such as agriculture and food […]*

1.4. Suppliers in the Digital World

A whole world of manufacturers and suppliers is in full swing to better position themselves in these markets of artificial intelligence and data processing. In addition to countries and numerous customers, Greenman identifies six types of players structuring this supplier architecture of the digital world (Greenman, 2018):

1. **Very large companies in all industrial and service sectors**; these include major financial institutions, large manufacturing groups (aeronautics, automotive), manufacturers of agricultural equipment that play a key role in precision agriculture, and large logistics and service companies; each of these major players is both a center of excellence in digitization and artificial intelligence to meet its own needs, but also very often in partnership with other players to sell their solutions and applications to others in their industry.

2. **Providers of digital and artificial intelligence-based solutions, specific to certain industries**, for example healthcare, agri-food, education, transportation, legal services, finance, are also involved in the development and implementation of digital and artificial intelligence solutions for their customers. They are called vertical vendors because they are specialized by industry.

3. **Vendors that offer solutions to companies in all sectors**; this category includes specialists in customer management or human resource management applications, cyber security applications, or specialized tooling (for example, social distancing measurement tools or applications and software dedicated to exposure notification and employee protection in the context of the COVID-19 pandemic (see "Kencee u2" by Noovelia, kenceertls. com), etc.) They are called horizontal vendors because they are specialized on the functions of the company, regardless of the sector.

4. **Model and algorithm vendors** who specialize in the development of functionalities such as facial recognition, vision, speech recognition, semantics, etc., are also known as horizontals because they are specialized in the functions of the company regardless of the sector. They are at the heart of artificial intelligence and bid data research and development. There are generally more scientists and researchers there than among other stakeholders.

5. **Providers of platforms and infrastructures** that support all these stakeholders with cloud computing, computing, and data processing services of all kinds.

6. **Suppliers of smart chips** and other components essential to the development of digital and automated systems based on artificial intelligence and algorithms.

The agri-food sector will have representatives from each of these categories of suppliers, as well as groups of suppliers from several categories, since the complexity and costs of developing and marketing products and services push competitors to cooperate by creating collaborative platforms that can be open and based on open-source software (see the initiative launched by Yara and IBM in Davos in January 2020).

1.5. The Impact of Digital and Artificial Intelligence on Productivity

The impact of the digitization of the economy and artificial intelligence on labor productivity is potentially very large. Several works have been carried out on this major topic including that of Purdy et al. (2016), the International Robotics Federation (2017), the International Telecommunication Union (2018), West et al. of Brookings (2018), and Chui et al. (2018).

All of these reports are quite convincing and agree that artificial intelligence is not just another technology like the Internet of Things or cloud computing, but a constellation of technologies; these new intelligent learners are increasing and even surpassing human capabilities since they are able to capture, understand, learn, analyze, decide and act. Research by the Accenture group (Purdy et al., 2016) has identified three ways in which artificial intelligence increases labor productivity. They are:

- **Intelligent automation**, which creates a virtual workforce that partly replaces human work, but also complements it; one only has to visit factories that use intelligent robots or a call center that uses intelligent algorithms to see the productivity gains that this virtual workforce provides (International Federation of Robotics, 2017; Atkinson, 2019).
- The **increase in human labor and human capital**: this is the case where artificial intelligence increases human intelligence, for example, in the diagnosis of diseases in

humans and animals, where systems based on deep learning can in a fraction of a second make use of the millions of data provided to them, and thus identify the patient's disease; the same kind of increased intelligence is seen in the insurance industry, energy infrastructure management and many other fields.

- **Dissemination of innovations**. Artificial intelligence is not a sector, an industry, or a technology, but a horizontal phenomenon that modifies all human activities; think of the impact that the widespread use of autonomous vehicles will have in transportation, but also in fields and agri-food factories.

Today, automobiles are on the move only 4% of the time and are therefore immobilized 96% of the time (Bates and Leibling, 2012; Barter, 2013); this capital is properly immobilized and is not in use. In fact, mobility in large urban centers is increasingly referred to as a service where a large number of autonomous, electric, interconnected and networked vehicles would be brought together in a single platform at the service of users, who will pay according to their use, taking into account duration, time of day and attendance. The same phenomenon of sharing robots and equipment in the fields and among farms is already starting to appear: it is Farming as a service (Bain & Company, 2018) that transforms the cost of capital acquisition by each farmer into a cost of renting the service; this concept already exists, but digital platforms allow sharing in a more optimal and personalized way, as each farm's data is protected and valued.

> *[…] economies [...] that do not adapt to this new technological and scientific revolution and do not adopt these new technologies will clearly be much less competitive and will find it very difficult to create wealth […]*

Accenture (2019) even goes so far as to predict that artificial intelligence will cause a 35% increase in productivity in the United States by 2035! While such predictions may raise doubts about the size of future labor productivity gains, studies by a large number of institutions such as the Organization for Economic Co-operation and Development (OECD, 2019), government agencies, think tanks (such as Noël, 2018), consultants (Frontier, 2018) and academics (Acemoglu, 2019; Frank et al., 2019; Korinek, 2019) on the impact of artificial intelligence on work and income distribution point to the existence of a very large scale and deeply disruptive phenomenon that has already begun to manifest itself. These studies identify sectors and jobs at risk as well as winning sectors and potential new jobs. They also identify the public policies that need to be put in place to mitigate the negative effects of this digital revolution and catalyze the positive effects. The finding is that economies (and the actors, agents of these economies) that will not adapt to this new technological and scientific revolution, and that will not adopt these new technologies, will clearly be much less competitive. They will find it very difficult to create wealth, which will also limit the means of their governments to support those who will be very negatively affected by this great upheaval. This point of view is also one of the highlights of the sectoral table of Canada's economic strategies in agri-food, held at the initiative of the Ministry of Innovation, Science and Economic Development, which emphasizes the imperative "to invest in innovation and strengthen competitiveness through increased automation and digitization" (Government of Canada, 2018).

1.6. Digital Transition as a Lever for Environmentally Responsible Transition

The digitization of commercial, industrial, and agri-food activities makes operations and processes more efficient and offers significant productivity gains. The digital world and the world of artificial intelligence are going to impose themselves just as the first three revolutions have ended up radically transforming economies and societies. The fundamental characteristic of this fourth revolution stems from the fact that any digitization operation, whether or not accompanied by the use of artificial intelligence, gives rise to the production of data at all stages of the processes of creation, design, decision-making, manufacturing, purchasing and distribution within the company, as well as between the company and its customers and between the company and its suppliers; so everything can be identified, measured and communicated. Data is essentially gold for the management and optimization of activities in all industries and, by its very existence, it reduces information costs and provides a level of transparency never equaled in the economy and society.

> *The supply chains of a digitized industry become transparent, as the traceability of the ecological footprint of each stage of the production process is identified by the data that digitization generates. This is where the link between the digital transition and the ecological transition is made.*

In a digital world, access to and exchange of information and data between the economic agents of a factory, a company and even an industry are therefore radically modified. Indeed, members of a board of directors as well as the regulators of an industry are now able to request and obtain a much higher level of information granularity with respect to data, information, and audit trails. This new context of transparency makes it easier to identify and measure the positive and negative externalities generated by economic activity. The supply chains of a digitized industry become transparent, as the traceability of the ecological footprint of each stage of the production process is implemented by the data generated by digitization. This is where the link between the digital transition and the ecological transition is made (Poore et al., 2018; Brady et al., 2019; Kaan et al., 2017).

Even if this information is private, regulators and governments in general may, through legislation or other means, require access to it. This means that the concerns of the public (who will also push for this data) and governments about the impact of industrial, agricultural and commercial activities on the environment, climate, public health, noise and scenic beauty will be better addressed in a digital world as this information will exist and will be available.

This increased degree of transparency may induce a defensive attitude on the part of the company, but, on the other hand, it may also incite it to seek a win-win solution for the private and the public and thus find its own interest. Indeed, in a world of information sharing, the regulatory approach to be favored will rather be the adoption of a joint risk management and prevention program to reduce negative externalities and favor positive externalities. The aim is then to move towards the concept of smart regulation (see Eisen, 2013; Zetzsche et al., 2018; Saiz-Rubio et al., 2020).

2. From Precision Farming to Digital Food Processing

2.1. The Demand and Supply of Digital Technology in the Agri-Food Industry

> *The demand for a digital revolution will therefore be strong and urgent because these technologies can help societies meet these many challenges [...].*

This great digital revolution is also going to impose itself in the world of agriculture and food, not primarily to reduce costs, increase profits or make the land more fertile, but because the technologies it offers are becoming, every day and in every country, part of the solution to the problems and challenges of the planet and its people. In 25 years, according to the United Nations (2019) the Earth will have more than 10 billion inhabitants, with an ever-increasing urban population. If this increase in the number of consumers translates mathematically into an increase in the demand for protein, it is salutary that this need is met by a more diversified diet including more organically grown plants, less sugar, less lactose and less carbohydrates. And this growing and diversified demand will have to be met at a time when the world's arable land area is not growing (Millman, 2015; Benke and Tomkins, 2017; Gerbet, 2018; World Bank, 2020), when youth are less and less interested in agricultural occupations (Fédération de la relève agricole du Québec, 2011; Radio-Canada, 2017; British Broadcasting Corporation, 2019; Rigg et al., 2020; Royer et al., 2020), that soil fertility is declining for many reasons (Vanlauwe et al., 2015; Wood et al., 2017) and that drinking water is becoming scarcer (World Wildlife Fund Canada, 2009; Leflaive et al., 2012). Moreover, these issues are part of an environmental crisis since the consequences of global warming are multiplying the frequency and amplitude of natural disasters around the world. All human activities will be affected by these impacts; among them, food production is a major contributor to greenhouse gas emissions and already suffers greatly from ecological upheavals (Kaiser et al., 1993; Bélanger and Bootsma, 2016; Mahdu, 2019; Praveen and Sharma, 2019; Alvi et al., 2020).

The demand for a digital revolution will therefore be strong and urgent because these technologies can help societies meet these many challenges, and because they can contribute to:

- Food supply for populations;
- Food safety and traceability;
- Facilitate the ecological transition of the agri-food sector;
- Make the industry more effective, resilient, and efficient for the benefit of all.

All the types of digital industry players we identified in the previous section (1.4) are therefore naturally present in the digital agri-food industry and are important players in its development. We will find them around the following three main themes of intervention:

1. **Precision agriculture** and **digital agronomy** by which multiple data are collected and transformed into valued information and management decisions;

2. **Supply chain optimization**, which aims to make all production, processing, and distribution processes from farm to fork more efficient and robust;

3. **Sustainable food** support systems where environmental and ecological dimensions are captured and analyzed.

These three themes are developed in the following pages.

2.2. Description of Technologies

2.2.1. Precision Farming

> *Precision farming, which consists of adopting the right growing practice on the right soil at the right time and with the right intensity.*

Sampling of agricultural soil characteristics began in the late 1920s, and it wasn't until 1963 that Matheron, a Canadian scientist, proposed geostatistical methods to measure variability in soil quality. For more than thirty years, discussions among experts focused on different sampling methods until laser and satellite technologies created a paradigm shift (see Zhang and Auernhammer, 2016). The first International Conference on Precision Agriculture was held in Minnesota in 1992, two years before the US government approved the legal civilian use of its military GPS (Global Positioning System) geolocation and navigation technology for military purposes. The first satellite network was launched in 1994. Very quickly, several agricultural equipment manufacturers offered farmers geolocation services that were initially not very effective, but which benefited from numerous iterations and technological improvements that perfected them. Today, even if the rate of adoption and use of these technologies depends on each country, the agricultural subsector, and the size of the farm, these systems have been greatly optimized and can equip the entire range of agricultural machinery; then it became precision machinery. Note that the two main factors in the adoption of GPS are farm size and income (Bélanger and Bouroubi, 2015; Royer et al., 2020). It is for these reasons that Quebec farms remain poorly equipped: all sectors combined, in 2016, 16% of them adopted GPS (Boudreau, 2018).

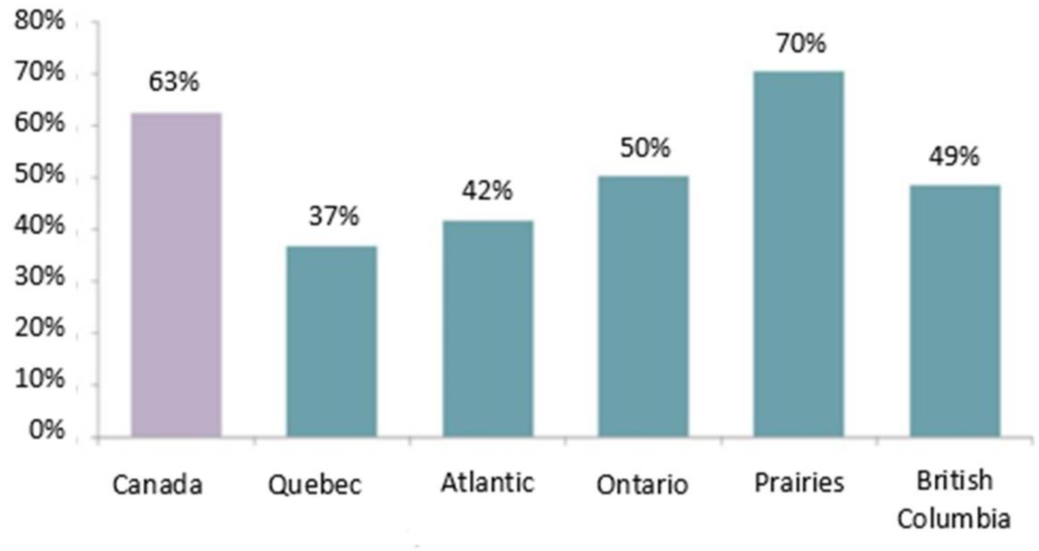

Figure 3 – Proportion of grain and oilseed farms using GPS technology (Boudreau, 2018)

Khosla and Mulla (2017) have documented the many innovations that have marked the development of precision agriculture, which consists of adopting the right cultivation practice on the right soil at the right time and with the right intensity. In addition to the role of soil sampling and geolocation, these authors recognized the importance of several innovations such as farming by soil, variable intensity fertilizers, variable rate herbicides, modulated irrigation, remote sensing, autonomous navigation of tractors and farm equipment, agricultural robotics and proximity sensing (UAVs) used by suppliers to optimize equipment for seeding, spraying and harvesting. Numerous demonstrations of this precision agriculture are highlighted in explanatory videos, for example the precision seed drills designed by the equipment manufacturer by John Deere (see https://youtu.be/sYyzyKkNZWs).

Khosla and Mulla (2017) conclude their history of precision agriculture by arguing that it is mainly technological innovations that have been significant since the beginning and not innovations in information analysis and management and decision support systems. It is primarily technological additions to farmers' work equipment that should be retained, since these analyses and decision support systems are not incorporated into the farming routine, but are rather used by seed and fertilizer distributors, consultants, and industry equipment manufacturers. Khosla and Mulla continue to anticipate an increasing use of digital and robotic technologies in seed, spraying and harvesting equipment.

This dichotomous vision between farmer users of smart equipment and professional users of the data produced by smart equipment dates from 2017. Although a foundation for technological developments in the sector, Precision Agriculture is only one component of the broader concept of digital agriculture, which includes not only the farm, the producer, his tools and machinery, but also all the other players and forms a complex ecosystem.

Digitization can also improve farmers' working conditions and reduce the environmental impacts of agriculture.

2.2.2. Digital Farming

While the digital revolution in manufacturing would have been so named in 2013, the publication of writings related to the digitization of industry, agriculture and food began in the late 1980s and will accelerate from 2016. While the literature concerning the agri-food sector appeared later than the publications concerning the manufacturing sector, the three key terms most used in these studies were sustainability, robotics, and the Internet of Things (see Demartini et al., 2018). It is very recently, in 2018, that the concepts of digital agriculture, digital agronomy and digitization of the agri-food sector have emerged strongly in scientific publications, public policy, and traditional and social media. In April 2019, the European Community issued its cooperation declaration on digital agriculture: A smart and sustainable digital future for European agriculture and rural areas (EU, 2019). This declaration clearly established the links between digital and the ecological transition of the agri-food sector. The document lists the benefits and obstacles to the digitization of the sector and proposes commitments by member countries to strengthen research in the field, establish infrastructures favorable to innovation, create a space for European data to feed intelligent applications for the agri-food sector while maximizing the impacts of these policies. In a subsequent publication, Shaping the evolution/digital revolution in agriculture (EU, 2020), the Commission is even clearer. We take the liberty of reproducing these few paragraphs of this brochure, which are very convincing:

> *Supporting a Digitized and Data-Driven Rural Europe*
>
> *Digital technologies can help European farmers to provide safe, sustainable, and quality food. Not only do they allow farmers to "produce more with less", but they can also contribute to the fight against climate change. New and existing technologies such as the Internet of Things (IoT), artificial intelligence, robotics and mega-data can help make processes more efficient and create new products and services.*
>
> *Digitization can also play a role in improving life in Europe's rural areas, as highlighted in the Cork 2.0 declaration that the use of digital technologies will be increasingly vital for farmers and other rural businesses to find sustainable solutions to current and future challenges.*
>
> *The European Commission (EC) aims to digitize the activities of the agricultural sector and rural areas in Europe and to build on this digital data. As part of the strategy for a digital single market, the communication entitled "Going digital for European enterprises" sets out its objective: to ensure that "every business in Europe, whatever its sector of activity, wherever it is located and whatever its size, can take full advantage of digital innovations to improve its products, enhance its processes and adapt its business models to digital developments. […]"*
>
> *Digitization for Agricultural Sustainability and Productivity*
>
> *Today, many farmers are already using digital technologies such as smartphones, tablets, in situ sensors, drones and satellites. These technologies offer a range of agricultural solutions*

such as remote measurement of soil conditions, better water management, and crop and livestock monitoring. By analyzing the data collected, farmers can better anticipate likely changes in crop patterns or animal welfare and health. This allows them to organize themselves more effectively and efficiently.

The potential benefits of using digital technologies can include improved crop yields and animal performance, optimized inputs, and reduced workloads, all of which can increase profitability. Digitization can also improve farmers' working conditions and reduce the environmental impacts of agriculture.

Another advantage concerns agricultural data flows. Improving the flow of information upstream and downstream of agri-food chains could bring many benefits to those involved, including farmers and actors in distribution and retail trade. All consumers, researchers, governments, and NGOs recognize the benefits of increased transparency. […]

Encouraging the Use of Digital Technologies

Digital technologies are easily accessible, but farmers do not all use them in the same way in Europe. This may be because many technologies require an initial investment and in some cases few tests are carried out in real conditions and specific geographical locations. In addition, these digital solutions are often considered complex, which may discourage their adoption. […]

The introduction and use of technologies require new skills and knowledge for farmers and advisors. Awareness raising and training at the regional/local level is essential, especially to reach small and medium-sized farms, where the use of digital technologies is not always perceived as profitable.

The development of specific data analysis tools, with a particular focus on cost effectiveness, can enable agricultural advisors to play a key role in informing farmers about digital technologies.

Europe's digital-ecological shift has had an impact on motivating researchers and industry stakeholders to further explore these links between the digital farm, the digital agri-food sector, and the ecological transition. The impact has been felt even in the Americas, as evidenced by the publication of Basso and Antle (2020) entitled Digital Agriculture to Design Sustainable Agricultural Systems, which is a real plea for a digital agriculture that goes beyond short-term concerns about the profitability of precision farming and repositions it in the service of sustainable development of the agri-food sector. In the week following its publication in Nature Sustainability, Forbes magazine took up the essence of the two authors' arguments (Kite-Powell, Forbes, 2020).

A group of Italian researchers (Bacco et al., 2019) has produced an excellent overview of digitization activities in agriculture and the smart farm. This document is essential reading for those who want to appreciate the benefits and barriers to digitization in the agricultural sector, as it provides an inventory of current projects, particularly in Europe, but also an overview of research activities, technology transfer models and tested methods to make these technologies easier to adopt by industry stakeholders.

In fact, Europe is an experimental laboratory for digital agriculture, and Quebec could draw inspiration from it both in terms of public policies implemented and technologies deployed, and in terms of business models and implementation and transfer tools.

One of the characteristics of the agri-food sector is the link between its ecological transition and its digital revolution; this link is reinforced by the digital architecture models already tested, such as the blockchain technology, which promotes transparency and facilitates trust between industry stakeholders. Let's take a closer look.

2.3. Spinoffs and Impacts of Digital Technologies on Agri-Food Chains

2.3.1. Supply Chain Optimization

In the 5 years prior to the breakup of COVID-19, North American consumers' food expenditures grew at a nominal annual rate of 4% (Felix et al., 2020); and was split roughly equally between purchases in stores (grocery stores or supermarkets) and purchases in restaurants, hotels, hospitals and schools. In Quebec, prior to the COVID-19 crisis this proportion has not yet been reached, since nearly 65% of food demand is for retail versus 35% for food service (MAPAQ, 2019).

Then suddenly, the "side effects" of the coronavirus radically changed this proportion. According to McKinsey (Felix et al. 2020), during the month of March 2020, in-store purchases rose by 29% while those in food service companies dropped by 27%, causing numerous cascading effects along supply chains: numerous cancellations on one side and a flood of new orders on the other with the expected results of rising inventories on one side and supply shortages on the other. All stakeholders in food supply chains were hit and, fortunately, apart from epiphenomena and one-off issues (Felix et al., 2020; OECD, 2020), consumers were able to satisfy their demand for food throughout the health crisis.

This health and economic shock, which has not yet subsided, forces us to recognize that not only has the food service sector been heavily hit, but all stakeholders have realized the paramount importance of robust and efficient supply chains.

In fact, the COVID-19 crisis accentuates supply chain issues that were already familiar to producers, wholesalers, retailers, restaurant and hotel operators; the high degree of complexity of the agri-food chain is leading to a widening gap between consumer demand for detailed, verifiable and quality information and the ability of producers, processors and distributors to provide this information simply, instantaneously and at low cost. The CIRANO 2018 Barometer (by Marcellis-Warin and Peignier, 2018) sheds light on the consumer's perspective, perceptions and expectations regarding online commerce and trade; in particular, Quebecers do not find all the information they need on products when they store online (40% lack information when they store online, while only 17% of customers lack information when they are in-store). In either case, this lack of information could be addressed with technologies that make use of QR codes.

To understand how these technologies work, let's take the example of a real estate transaction. When a house is sold, the transaction is registered at the registry office, which confirms that it did take place, at what price, and who was involved.

> *In many agri-food chains, information on compliance with government regulations or procedures required by customers is still recorded on paper or in centralized databases [...].*

Before the transaction was completed, it was reviewed by a notary who checked other records for the validity of the land registry, the name of the homeowner, etc.; the bank also checked the buyer's creditworthiness in its records and other credit files before granting a loan. There are many different registers, and the function of each one is to certify the truthfulness of the information contained in them so that transactions can be made with confidence. The same real estate transaction performed by blockchain technology would be instantly performed on a single registry shared by all agents involved in the transaction. The veracity of this registry would be guaranteed by its transparency, as it would be totally accessible and verifiable by all those who share it and could not be modified without the consent of each of the parties involved.

The blockchain technology became known through Bitcoin and has since become increasingly important in the financial and industrial sectors, but it is also attracting more and more interest from governments (Moné, 2019; Owens, 2017). Many of these government initiatives relate to areas such as currency and payment systems, real estate transaction recording, public health systems, identity management, etc. (Moné, 2019; Owens, 2017). The Government of Quebec has also announced plans to provide Quebecers with a digital identity that will use blockchain technology.

> *These consumer demands [for safety and sustainability] have been amplified by this health crisis, both on the domestic and international markets.*

In many food chains, information on compliance with government regulations or customer-required procedures is still recorded on paper or in centralized databases, which leads to numerous problems. The costs of handling this information are high, these manual processes are inefficient and allow for fraud, corruption, and errors, thus preventing or slowing down validation (Badia-Leis et al., 2015; Charlebois et al., 2016; Dandage et al., 2017; Tian, 2017; Tibola et al., 2018; Soon et al., 2019). This makes it costly to produce certificates of origin for the products or ingredients that have been used; such manual processes are also associated with data loss and lack of tracking of payment transactions. In such a context, it is impossible to meet consumer and wholesaler demands for food safety (accessibility and availability), food quality (edible and health), food sustainability (ecological footprint), origin (local content of products) and credible assurance of supply in an efficient and resilient manner.

These consumer demands have been amplified by this health crisis, both on the domestic and international markets. Even more clearly, even if all Quebec farmers became champions of precision agriculture, if they are not included in intelligent supply chains, they will be downgraded by foreign competitors both on international markets and on their own domestic market. This realization of smart supply chains is now widespread, and the goal is to build supply chain management processes that are transparent, auditable, and resilient. Modern agriculture is therefore based on the implementation of production and data sharing systems that, while protecting the privacy and confidential information of each stakeholder in the sector, meet customer information requirements for traceability from the farm to the table.

> *Smart contracts are encoded contracts that trigger a series of events that are automatically executed in the supply chain if certain predefined conditions occur.*

For this reason, blockchain technology is increasingly emerging as the keystone to solving food traceability issues, and as a major component in the implementation of intelligent supply chains using intelligent contracts.

Smart contracts are encoded contracts that trigger a series of events that are automatically executed in the supply chain if certain predefined conditions are met (Flores et al., 2020). A smart contract can never be altered once it has been implemented in the system. If an error has occurred and a change to the contract is required, all network stakeholders must be informed, and all must approve the change. Figure 4 from Flores et al., 2020 illustrates an example of a smart contract between an association of rice producers and their distributors. In this example, there are 6 steps in the execution of the contract that are automated and increase mutual trust between stakeholders.

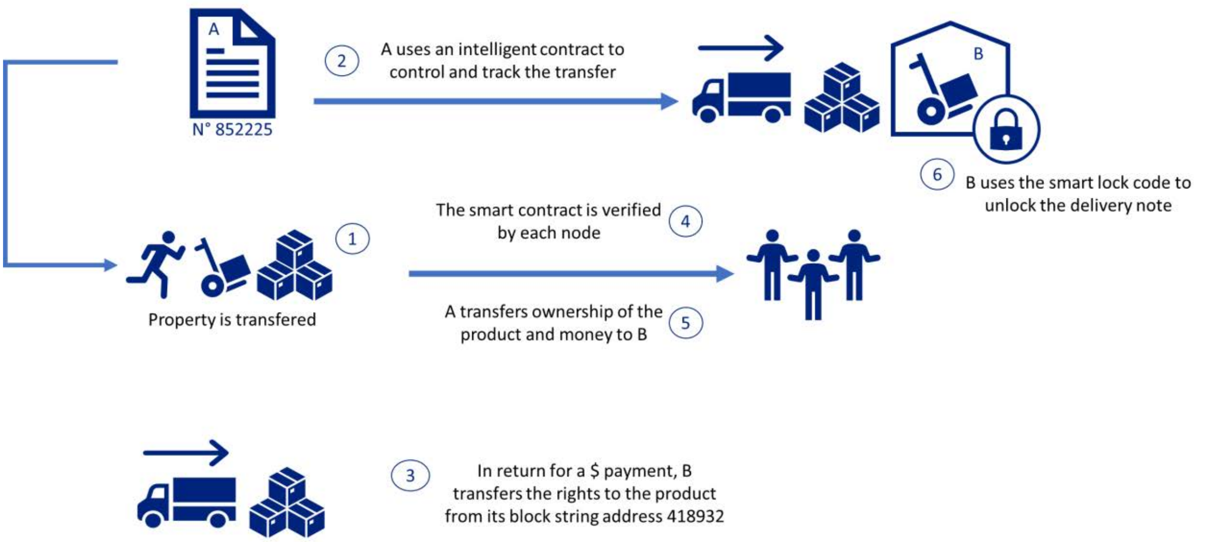

Figure 4 – Smart contract model for agri-businesses (from Flores et al., 2020)

Figure 5, also borrowed from the same publication, illustrates a blockchain model of supply chain participants.

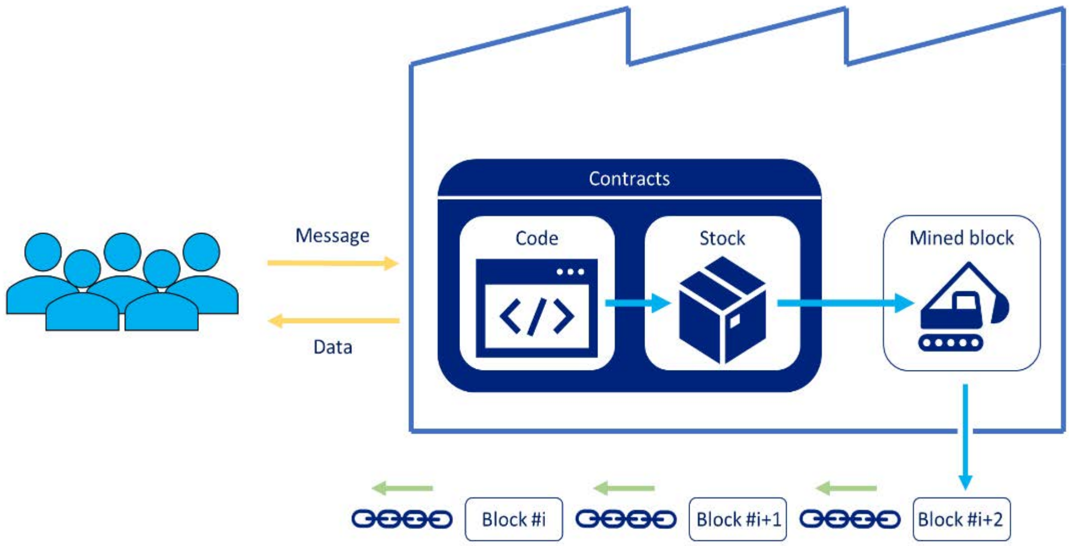

Figure 5 – Security of transactions with the blockchain (from Flores et al., 2020)

Although the scientific and technical literature has been quick to identify the blockchain as the desirable type of technological architecture for the digitization of agri-food supply chains, it must be recognized that we are at the very beginning of the commercial application of this technology. Let's look at three examples. One of the best-known applications is the IBM Food Trust, which has been tested, among others, with the participation of Walmart to track the origin of mangoes. According to the test, identifying the origin of mangoes can take up to 7 days without such a system, while the IBM Food Trust (ibm.com/blockchain/solutions/food-trust) identified the origin of the mangoes in 2.2 seconds. Provenance (provenance.org/tracking-tuna-on-the-blockchain) is another company that promotes a blockchain type traceability system for fish; each fish is identified by a unique digital tag that contains all the information about the path taken by the fish: fishing, packaging, transport, storage, etc. In Quebec, such projects exist but are still very rare, such as the joint initiative of Agri-Traçabilité Québec and the Beef Quebec program (https://www.atq.qc.ca/fr/accueil/l-actualite-en-revue/513-la-chaine-de-blocs-sera-testee-dans-l-agroalimentaire-d-ici). Below, Table 1 presents a list of companies and commercial products using blockchain technology in the agri-food sector.

Table 1 – Companies and websites promoting blockchain solutions for agricultural sector supply chains (from Demestichas et al., 2020)

Company or Commercial Product	Website
AgriChain	https://agrichain.com
AgriDigital	https://www.agridigital.io
AgriLedger	http://www.agriledger.io/about/
ATQ et Bœuf Québec	https://www.atq.qc.ca/fr/accueil/l-actualite-en-revue/513-la-chaine-de-blocs-sera-testee-dans-l-agroalimentaire-d-ici
arc-net	https://arc-net.io
Bühler Smart Supply Chain	https://digital.bruhlergroup.com/smartsupplychain/
Connecting Food	https://connecting-food.com/
Demeter	https://demeter.life
DOWNSTREAM	https://www.down-stream.io
Etherisc	https://etherisc.com/
Fishcoin	https://fishcoin.co
Honeysuckle White	https://www.honeysucklewhite.com
IBM Food Trust	https://www.ibm.com/blockchain/solutions/food-trust
Provenance from Shore to Plate	https://www.provenance.org/tracking-tuna-on-the-blockchain
Ripe.io	https://www.ripe.io
TE-FOOD	https://tefoodint.com
Worldcovr	https://www.worldcovr.com/

Finally, it should be noted that Kamilaris et al. (2019) listed several projects for the implementation of blockchain technology, specifying their level of maturity (from concept to integration into operations) and the needs of the agricultural commodity chains concerned. Clearly, the benefits of these new technologies are potentially very great, as the following representation (Figure 6), from a white paper published by the Ukrainian consulting firm Intellias (2020), illustrates very well.

Figure 6 – Illustration of a borderless ecosystem for business and farmer integrators (from Intellias, 2020)

2.3.2. Sustainable Food and Local Origin of Goods

The example of Patates Dolbec illustrates very well how the experience of merchants and consumers is greatly enhanced by the digitization of the company. Indeed, thanks to the numerous data resulting from digitization, the traceability of the product from farm to table is complete and provides an unequalled level of transparency to consumers and merchants.

Thanks to the use of simple barcodes, they can know the exact origin of the product. Moreover, the producer has perfect control over the quality of his product and can, if necessary, recall a particular batch of potatoes, because he knows who bought what, when, and from which batches the potatoes came. The scientific literature is burgeoning with examples of food and manufacturing companies that have already integrated such traceability practises (see Wolfert et al., 2017; Petrillo et al., 2018; Poore et al., 2018; v. Schönfeld and Bittner, 2018; Bach and Mauser, 2018; Saiz-Rubio and Rovira-Más, 2020).

In addition to tracing the origin of products (see Rousseau's Blue Basket and CIRANO, 2020), digitization provides a wealth of data that would make it possible, in principle, to measure the relative importance of local and imported inputs at each stage of the production, processing and distribution processes. But how can all economic activity be digitized in such a way as to capture this immense amount of data, and share it in a standardized and secure way between consenting stakeholders, while respecting the confidential and strategic nature of personal data and that of sometimes competing companies? This is where decentralized distributed registry technologies (the chain of blocks) come into play (Fernandez-Caramés et al., 2019; OECD, 2019).

More recently, the application of this technology to the agri-food sector has spread so that we can now refer to very educational presentations of this application (Stefanova et al., 2019) as well as overviews of the many implementation projects around the world (Kamilaris et al., 2019). The document e-Agriculture in action – Blockchain for agriculture: opportunities and challenges produced in 2019 by the Food and Agriculture Organization (FAO) and the International Telecommunication Union (ITU) provides an excellent analysis of the blockchain technology, its different variants and the challenges associated with its implementation through an overview of several digitization projects currently underway in the agri-food industry.

> *The great advantages of this version of blockchain technology are transparency, speed, efficiency, robustness, and safety.*

It should be noted at the outset that on a blockchain platform, the information would be recorded on highly secure registers that would protect the confidentiality of the information of the companies and individuals involved, due to the type of network used. In the world of distributed registry technology, there is a fundamental distinction between public, private, and federated networks (Casino et al., 2019). In the context of the application of this technology to agricultural and agri-food chains, the chosen network would normally be private or federated because these types of networks are more secure than public networks and allow stakeholders, buyers and sellers, to know each other. In addition, these types of networks are very efficient, less energy intensive and able to approve transactions and information almost instantaneously. However, since the federal and provincial governments – if only because of their role in food regulation – would be stakeholders in all these private networks, the governance and management mechanisms would make them federated networks.

The major advantages of this version of blockchain technology are recognized here as being transparency, speed, efficiency, robustness, and safety. The implementation of this technology, however, requires an approach that mobilizes all components of the ecosystem of the food supply chain under consideration where the decentralized distributed registry will be applied. In an ideal scenario:

- Governments would be leaders in the adoption of this technology;
- Industries would use the technology first to optimize their supply and distribution chains;
- Civil society would come to accept and trust him if it is convinced that it respects the privacy of individuals.

This is, fortunately, a strong point of this technology used in a private or federated network (thus this characteristic will avoid, for example, that competitors will be able to calculate the profit margins of the other companies that will participate in this private and federated network).

In addition, in the context of the health crisis, the growing concern of consumers and distributors about the quality and safety of the food and products they buy, as well as new rules governing international trade treaties, the countries importing our products, food and services are increasingly demanding full traceability of the goods we offer them. Our international clients, like Quebecers, want to know the origin and exact composition of the inputs used to produce the goods and products offered to them. The digitization of agri-food activity using shared registry technology is an essential step in their traceability.

In 2020, managing an agri-food, manufacturing or service business necessarily implies managing an increasingly technological business and therefore the technological risk is added to the usual financial and business risks. Managers and their shareholders must therefore decide on the degree of digitization, connection, automation, and the level of security they wish to implement in order to remain competitive and ensure the sustainability and growth of their company. This new business paradigm, full of promise, allows for a renewal of the ways in which goods and services are created, produced and distributed, but it also imposes a cultural, organizational and financial shift that requires boldness, risk taking, more capital and the hiring of new skills.

While there is no doubt that the digitization of the agri-food sector will be extremely beneficial in many ways, there are several challenges and obstacles to its realization. The next section of this paper focuses on these barriers.

> *Every digitized manufacturing and agri-food activity and every digitized service process remains in continuous communication with other objects and other agents so that data is constantly being produced and exchanged. Data becomes gold for understanding issues and making decisions.*

The Importance of Data

The entire world is at the heart of a digital and scientific revolution, and customers in Quebec as well as those in the regions and countries where we export expect high-quality products and service adapted to the digital age. Advances in Industry 4.0 and digitization are redefining corporate supply chains and optimizing production processes while shifting the sources of value creation. Every digitized manufacturing and agri-food activity and every digitized service process remains in continuous communication with other objects and other agents so that data is constantly being produced and exchanged. Data becomes gold for understanding issues and making decisions. This data production has and will grow dramatically as all sectors of the global economy become digitalized and as blockchain, artificial intelligence, virtual and augmented reality technologies become more widespread. The number of interconnected objects already stands at 25 billion and is expected to triple by 2025! This is the main source of productivity growth in the years to come. This revolution will take a quantum leap when 5G communication technologies are deployed, as data collection capabilities will be almost infinite and data transfer will be exponentially faster (Burke, 2019; Pansanen et al., 2020).

3. Challenges and Barriers to Digitization in the Agri-Food Sector

The digitization of the agri-food sector is a marathon that has just begun and where runners benefit from continuous improvements in science, new technologies and each other's experience. But it is also an obstacle course. By far the most important issue at stake is the connectivity of Quebec's agricultural territories. It is followed by the other digitization challenges in the world that can be grouped into two broad categories, as Bacco et al. (2019) do: technical challenges and non-technical challenges that are more of an organizational and cultural nature.

3.1. Connectivity in Agricultural Territories: An Alarming Situation

The first technical challenge in digitizing Quebec's agri-food sector is undoubtedly the fact that many farms do not have access to Internet service and that in too many regions high-speed connectivity is not available or not efficient. As documented in Appendix 1, it is estimated that one quarter of Quebec farmland does not have adequate Internet connectivity (unserved or underserved). In fact, this finding becomes even worse when considering the Canadian Radio-television and Telecommunications Commission (CRTC) connectivity criteria: nearly 70% of the agricultural land described as "well served" actually has measured speeds below the minimum threshold (upstream flow).

> *One quarter of Quebec's farmland does not have adequate Internet connectivity (unserved or underserved). In fact, this is even worse when considering the connectivity criteria of the Canadian Radio-television and Telecommunications Commission (CRTC): nearly 70% of the farmland qualified as "well served" has measured speeds below the*

As documented in the Digital Ubiquity Capital report (reproduced in Appendix 2), the challenge of connectivity in agricultural areas in Quebec is significant. Connectivity criteria established in Canada by the CRTC require a minimum wireless service speed of 25 Mbps for downloads (upload) and 5 Mbps for uploads (download). For wireline infrastructures, the minimum capacity must be 50 Mbps for downloads and 10 Mbps for uploads.

Applying these CRTC criteria to the geographic data in the Reported Agricultural Parcel and Production Database (RAPPD), Digital Ubiquity Capital's experts came to three conclusions:

1. More than 23.4% of Quebec's agricultural land is in areas that are unserved or underserved in terms of connectivity;

2. Of the 76.6% of farmland located in areas considered well served under CRTC criteria, data from connectivity tests conducted by the Canadian Internet Registration Authority (CIRA) show that 68.3% of farms in these areas actually receive Internet service below the minimum 25 Mbps download criteria;

3. Of the 23.4% of farmland located in unserved or underserved areas, 93.3% of these farms receive Internet service below the minimum 25 Mbps criterion, again according to CIRA's tests.

Table 2 – Internet Connectivity and CIRA Performance Tests on Farmland in Quebec (from Lemay and Digital Ubiquity Capital, 2020)

Agricultural Land Connectivity Category (CRTC)	Proportion of territories (CRTC)	Proportion of region category (CRTC) with speed measurements (CIRA) below 25 Mbps (upstram)
Well-served areas	76,6%	68,3%
Unserved or underserved areas	23,4%	98,3%

Note : Digital Ubiquity Capital's document is available in Appendix.

As indicated by the CRTC, the minimum level of connectivity of 25 Mbps – while perfectly adequate to allow citizens to access e-mail and participate in teleconferencing sessions – is insufficient for the technological requirements of precision farming, cloud computing and digital agriculture. Indeed, digital agricultural applications increasingly require symmetrical upload and download capabilities where upload and download Internet speeds are similar. This symmetry has become essential for applications involving data analysis, teleconferencing with partners, application updates and the transmission of information collected for real-time verification.

Digital agricultural applications increasingly require symmetrical upload and download capabilities with similar upload and download Internet speeds.

3.2. Technical Challenges

It is now clear that the digitization of agri-food requires the use of almost all the technologies associated with the digital revolution such as sensors, RFID, the Internet of Things, mega-data, robotics, drones, remote sensing, cloud computing, artificial intelligence, low frequency communication networks, etc. Similar to Patates Dolbec's digitization approach, the Smart Farm and its digital supply chain ecosystem require a network of sensors, automated control systems, satellites for location, warehouse capabilities, data analysis skills and multifunctional UAVs.

However, the complexity of the agricultural environment often poses technical challenges. For example, sensor networks must be able to withstand wide variations in temperature, be placed at different depths in the soil, be able to transmit data accurately, limit energy costs, and not require frequent maintenance. This sensor challenge also exists for animal traceability, as too often the identification tags on the ears of animals are lost in the field. In many agricultural sectors (e.g., small fruits and vegetables, chicken, or milk), there are no serious problems associated with sensors.

> *The question of the ownership of this data is then raised as well as the rights to use this data for the stakeholders in the supply chain networks.*

It should be remembered that once captured, these data must be communicated on the Internet networks of the objects which are then solicited from the point of view of their capacity, security and protection of private data belonging to producers or processors. The question of the ownership of these data is then raised as well as the rights of use of these data for the stakeholders in the supply chain networks. Trade-offs arise between retaining data for competitive protection and sharing data for access to the best industry findings and practices. Each supply chain must, in fact, adopt a policy on data ownership and sharing.

Once the barriers associated with data capture, proper and efficient data transmission and ownership are removed, the analytical tools and systems must be built and integrated with other digital platforms on the farm, in the processing plant or in the supply chain. This is where the incompatibility between solutions offered by different vendors becomes another critical technical issue. The CIRANO report on digital agriculture addresses these issues of interoperability, standardization, autonomy, and independence of farmers with respect to their technological choices (see Royer et al., 2020). This enumeration of technical challenges is incomplete, and these obstacles could be further explored. Bacco et al. (2019), Demestichas (2020), Kamilaris (2019), and Kosior (2018) do indeed make a more complete census.

In practice, the digitization and blockchain projects underway in the agricultural world are open-air laboratories, and they show that some agri-food chains are easier or more straightforward to digitize than others. It also shows that technologists succeed over time and with the necessary investments to meet the technical and technological challenges. These discoveries become available quickly in the form of new commercial applications that are then purchased and implemented by those who are already running the marathon of digitizing their agri-food sector.

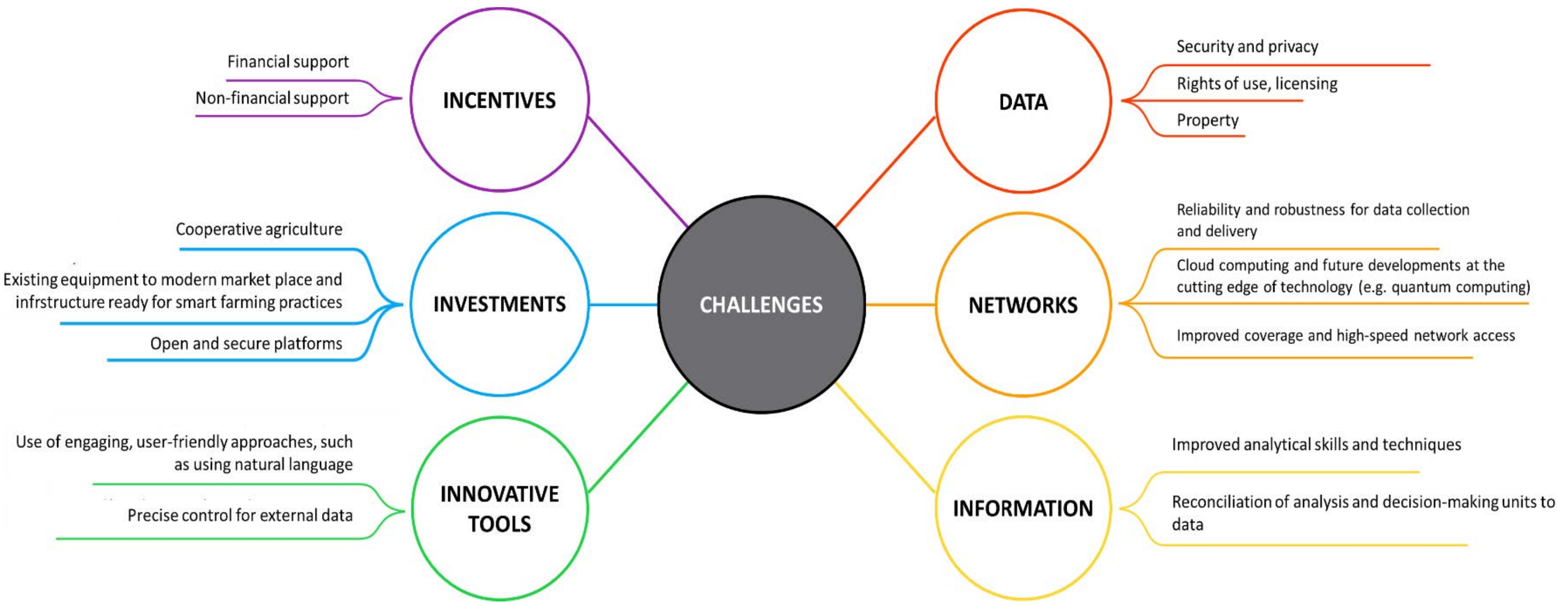

Figure 7 – Key challenges of digital agriculture (adapted from Bacco et al., 2019)

3.3. Organizational and Cultural Challenges

> *In Quebec, the organizational and cultural challenges and obstacles to the digitization of agri-food are very present; they are not different from those identified elsewhere in the world, particularly in Europe, where public policy has made the digitization of the agri-food sector a priority.*

Precision agriculture, which is manifested by sophisticated and intelligent agricultural equipment in fields, barns, or slaughterhouses, is well present in a few sectors that in Quebec show good profit margins such as milk or chicken. In addition, in the sectors where traceability is imposed by regulation (see Agri-Traçabilité Québec) we also find components or initiatives of digitization. But as we established earlier, precision agriculture, although indispensable, is not sufficient to digitize the sector, because it is the ecosystems of each sector that must be digitized in order to meet the quality, health, traceability and sustainability requirements of customers.

In Quebec, the organizational and cultural challenges and obstacles to the digitization of the agri-food sector are very present; they are no different from those identified elsewhere in the world, particularly in Europe, where public policy has made the digitization of the agri-food sector a priority.

In fact, the observation made by observers (Bacco et al., 2019) can be summarized in three types of non-technical challenges:

1. The first concerns **investments** arising from the need to depreciate more rapidly equipment and software that is no longer compatible with new technologies; this involves **financing new technologies and new, more modern equipment**.

2. The second relates to the challenges related to the implementation of new tools and **staff training** while seeking to promote the **most pedagogical approaches to data sharing issues**.

3. The third concerns the development of **financial incentives** and **non-financial support programs** that governments must put in place to encourage the digital development of each sector.

Conclusion and Recommendations

The major strategic objectives considered by MAPAQ are:

1. Promote local purchasing;
2. Increase the food supply from Quebec producers;
3. Strengthen supply chains;
4. Accelerate the greening of the agri-food sector.

These major strategic objectives are highly relevant because they are fully aligned with the expectations of Quebec consumers who are looking for quality food that is good for their health and whose origin they can identify in order to eat more locally and reduce the ecological footprint of their consumption habits. Quebecers, like export customers, also want to be able to count on robust and resilient supply chains. These objectives are also compatible with the needs of foreign consumers who want to trace the origin of the food they are offered, as well as being able to verify the ingredients and processes used to produce it. These new expectations are widespread here as elsewhere and have been amplified by this pandemic, which has heightened the need for food safety and quality.

To achieve these objectives, it is essential and unavoidable to produce information that is verifiable and accessible to all stakeholders in an agri-food sector; this information can only be obtained from data resulting from the digitization of food production, processing and distribution processes. Agri-food data is gold, the gold mine is this agri-food ecosystem and its digitization is the only way to extract the ore. It is essential for all the players in the agricultural production chain to understand that the core of their business is no longer just food production, but also, and perhaps above all, that they are data producers. To this gold mine will naturally be added the "foundry", i.e., the fabric of young technology companies that are and will be experts in the valorization of these data. Developing this know-how can only be done by stopping the leakage and monopolization of data by third parties, as well as by promoting their openness and sharing. Quebec's food sovereignty and the implementation of sustainable agriculture are therefore conditional on the guarantee of agri-food data sovereignty and the establishment of a sustainable data governance model.

Digital is not a sector of the economy or agriculture, but an industrial revolution that is a must for Quebec, as it is for all societies.

A very good example of how traceability works in a world based on a blockchain architecture is the one that European food and mass retail giant Carrefour applied to the chicken sold in its hypermarkets (see https://youtu.be/79qdAutt-Fg). In this example, the consumer has quick access to a multitude of information via his smartphone by simply reading the QR code (Quick Response code), which takes him directly to a portal dedicated to traceability. The consumer is informed of all the relevant details concerning the location of the breeder and the history of the chicken's breeding and the ingredients that fed it; he also learns about the chicken's journey from the hatchery to the slaughterhouse as well as its transport to the warehouse and to the point of service.

Armed with this information, the consumer can decide to make this local and good quality purchase (objective No. 1). The French producer is likely to see his competitive ability improved because the data about his product is now digitized; this data is accessible to all consumers and his products are now listed on a digitized supply chain. With the QR code, he will be able to provide his consumers with a personalized customer experience such as agritourism activities, recipes, bulk purchases, etc. (target No. 2). All stakeholders involved in the blockchain set up by Carrefour see their supply chain strengthened because, both upstream and downstream, secure data enables all stakeholders to optimize their links with their suppliers and distributors: in the event, for example, that one of the nutrients used in the feed of a batch of chickens turns out to be of poor quality, it will be easy for all the players in the chain to make a specific recall of the contaminated batch concerned because the number of each chicken and each batch appears on the invoices of distributors and consumers (objective No. 3). Finally, thanks to the QR code, it is possible to provide all the data to measure the ecological footprint of each chicken by identifying the costs of energy used, transportation costs and other relevant information from the analytical tools and multiple sensors installed in the farmer's intelligent hatchery (objective No. 4).

If the digitization of agri-food chains is the key to achieving the four major objectives aimed at advancing Quebec's agri-food sector, it is also an essential defense strategy to ensure the survival of distribution networks in our own domestic market and to enable our producers to move their products through the supply chains of external markets.

The first section of this document was devoted to a long presentation on the new business models of the digital world and the new industrial dynamics that are shaking up its manufacturing and distribution. This section is an integral part of the argumentation. It was explained in this first section that Amazon, Walmart, and a few others were in fact becoming platforms of platforms. Amazon's purchase of Wholefoods is not the purchase of a food provider for Amazon's customers, but the integration of a customer that will allow Amazon to understand, develop and optimize its platform for serving food retailers, whether they are owned by Amazon or a competitor of Wholefoods. It is to be expected that Amazon will soon offer its platform services for grocers as Amazon already offers distribution and supply management services for a very large number of hardware stores, bookstores, manufacturers, etc.

How will the major food chains in Quebec and Canada react when Amazon, which already has 14 grocery customers in Canada, will be able to offer them effective, efficient, and competitive distribution and supply management services? To a lesser degree, Couche-Tard is also an example of this new industrial dynamic. Why is Couche-Tard so successful? It's because every day it is becoming an increasingly effective and efficient platform to serve and serve convenience stores around the world!

> *[Digitization], an essential defense strategy to ensure the survival of distribution networks in our own domestic market and to allow our producers to move their products through the supply chains of external markets.*

We already know that Quebec is not home to any major manufacturers of precision agricultural equipment or robots that have begun to invade the agri-food sector (nor Canada, for that matter). These machines, equipped with sensors of all kinds, record billions of pieces of data every day in barns, fields, and slaughterhouses. While some of this data is being used to make our farmers, slaughterhouses, and food processing plants more efficient and effective – and that's good – these same machines are potentially transmitting data to their designers. In a digital world, the lifeblood of economic warfare is the ownership of all this data that feeds into the machine learning algorithms that will be used to optimize operations and distribution chains. If food distribution and the data it produces on consumer preferences and lifestyles come under the effective control of the digital giants, it will become very difficult for Quebec to implement agricultural policy objectives. All this also becomes very paradoxical, given the advantageous strategic position of Quebec and Canada in artificial intelligence!

> *In a digital world, the nerve center of economic warfare is the property of all this data that feeds the machine learning*

The concepts of food sovereignty, food self-sufficiency or food autonomy in a digitized world become very relative concepts if digitization is done entirely by manufacturers of intelligent machinery controlling food production data and by digital giants controlling distribution data. Therefore, the sovereignty of agricultural data is a sine qua non-condition for Quebec's food sovereignty, requiring the rapid development of a strategy to avoid the loss of these "computerized commodities".

One of the major challenges of digitization is not only the ownership of data, but also the protection of privacy and liberties. On this subject, the federal government recently published a statement of its policy on the subject (Government of Canada, 2020) which should provide food for thought for the Quebec agri-food sector.

Many deplore the fact that digitization and robotization are destroying jobs and accentuating inequalities. It must be recognized that technological changes, while increasing productivity, make winners and losers; therefore, it is essential that public policies accompany these technological changes with training and transition programs for the workers who will be the victims. Several companies are successfully making the digital transition by retaining the staff they train to work with new technologies: the case of Patates Dolbec is a good example. This issue of available continuing education, adequate initial training, and recruitment of the next generation of agricultural workers is another crucial element in the success of the sector's digital transition. The training and retention of experts in automated systems design and data analysis in order to develop technological solutions for the Quebec agri-food industry is another element to consider.

> *The concepts of food sovereignty, food self-sufficiency or food autonomy in a digitized world become very relative concepts if digitization is done entirely by manufacturers of intelligent machinery controlling food production data and by digital giants controlling distribution data.*

That is why the solution is not to reject this change; there is no point in waging war on it; rather, we need to make it an ally, otherwise our ability to remain competitive and sell in external markets and even in our own markets will be reduced to the point of being the losers.

The digitization of Quebec's agri-food industry is therefore an indispensable and unavoidable lever for achieving MAPAQ's major objectives. To achieve these objectives through the digitization of the sector, we propose the following five recommendations.

FIVE RECOMMENDATIONS

First Recommendation

Make digitization of the agri-food sector the priority of MAPAQ's strategic plan, both to attack domestic and international markets and to enable producers and distributors to defend their share of domestic and international markets.

Second Recommendation

Guarantee access to high-speed Internet services throughout Quebec. This is an essential condition for the digitization of the agri-food sector. By applying these CRTC criteria to the geographic data in the Reported Agricultural Parcel and Production Database (RAPPD), Digital Ubiquity Capital's experts have come to three conclusions:

More than 23.4% of Quebec's farmland is in areas that are unserved or underserved from a connectivity perspective.

Of the 76.6% of farmland located in areas considered well served according to CRTC criteria, data from connectivity tests conducted by the Canadian Internet Registration Authority (CIRA) show that 68.3% of farms in these areas actually receive Internet service below the minimum 25 Mbps download criteria;

Of the 23.4% of farmland located in unserved or underserved areas, 93.3% of these farms actually receive Internet service below the minimum 25 Mbps criterion, again according to CIRA's tests.

This situation is urgent, and its resolution is essential for the digitization of Quebec's agri-food sector.

Third Recommendation

Establish an inventory of the agri-food sector from the point of view of digitization for each sector. This work has already been initiated in CIRANO's study *Les enjeux du numérique dans le secteur agricole – Défis et opportunités*, and should be continued in the same vein. This inventory should make it possible to classify the agri-food sectors according to their degree of access to high-speed Internet, according to regulatory and market requirements concerning traceability, the degree of digitization of the sector, etc. Establish an order of priority of the sectors to be digitized according to costs and benefits.

Fourth Recommendation

To create with the agri-food sector and academia a monitoring center for agri-food blockchain technology implementation projects around the world, with priority given to projects that are the most relevant according to the order of priorities selected by MAPAQ. Initiatives, proofs of concept and implementations in Europe (such as Connecting Food, https://youtu.be/Yy2b2VBsrag) or the United States (see Arkansas Blockchain Technology Summit, 2018) will be highly relevant.

Fifth Recommendation

Mobilize a team of experts to support the MAPAQ in its strategic approach to implement blockchain technology for the digitization of Quebec's agri-food industries. Adapting the agri-food sector requires a spiral approach. Digitizing the agri-food sector is a bit like building a spiral staircase in the middle of an already built multi-storey house! Having electricity everywhere in the house will be essential (high speed), the inventory of fixtures will be crucial (knowing the channels) and seeing what has been done elsewhere is paramount (project monitoring). The staircase model is the spiral staircase because it is a customer requirement (transparency and data security require blockchain technology). Just like building a house, it is therefore necessary to involve experts and be accompanied by specialists in information and digital technologies. Adapting Quebec's agri-food sector by adopting an approach using blockchain technology requires the skills of experts to build the desired architecture, develop the digitization plan and carry it out with the industry over several years.

Bibliography

Agence France Presse, and Radio-Canada. 'Apple écope d'une amende record de 1,7 milliard $ pour pratiques anticoncurrentielles'. *Radio-Canada.ca*. 16 March 2020. https://ici.radio-canada.ca/nouvelle/1667969/apple-amende-record-pratiques-anticoncurrentielles-france-europe.

Agri-Traçabilité Québec (ATQ). 'Les lois qui régissent la traçabilité', 2011. https://guide.atq.qc.ca/fr/ong1-07.html.

Agri-Traçabilité Québec (ATQ), and Boeuf Québec. 'La Chaîne de Blocs Sera Testée Dans l'agroalimentaire d'ici', 2018. https://www.atq.qc.ca/fr/accueil/l-actualite-en-revue/513-la-chaine-de-blocs-sera-testee-dans-l-agroalimentaire-d-ici.

Agri-Traçabilité Québec (ATQ), Conseil Québécois de l'horticulture (CQH), Ministère de l'Agriculture, des Pêcheries et de l'Alimentation (MAPAQ), and Agriculture et Agroalimentaire Canada (AAC). 'Répertoire des solutions technologiques en traçabilité horticole'. Agri-Traçabilité Québec (ATQ), January 2014. https://www.atq.qc.ca/images/docs/fr/Production_horticole/Projet_pilote_horticole/Repertoire_Fr-FinalWeb.pdf.

Alvi, Shahzad, Faisal Jamil, Roberto Roson, and Martina Sartori. 'Do Farmers Adapt to Climate Change? A Macro Perspective'. *Agriculture* 10, no. 6 (June 2020): 212. https://doi.org/10.3390/agriculture10060212.

Ansip, Andrus, Tibor Navracsics, Phil Hogan, Mariya Gabriel, and Commission Européenne (CE). 'Déclaration commune: assurer l'avenir numérique de l'Europe'. Commission Européenne - European Commission, 2019. https://ec.europa.eu/commission/presscorner/detail/fr/STATEMENT_19_2070.

Association des détaillants en alimentation du Québec (ADA), and Ministère de l'Agriculture, des Pêcheries et de l'Alimentation (MAPAQ). 'Guide d'application - Indication de l'origine des fruits et légumes frais'. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation (MAPAQ), 2018. https://adaq.qc.ca/suivi-des-dossiers/agroalimentaire/reglement-sur-lorigine-des-fruits-et-legumes/.

Atkinson, Robert D. 'Robotics and the Future of Production and Work'. Information Technology and Innovation Foundation, 15 October 2019. https://itif.org/publications/2019/10/15/robotics-and-future-production-and-work.

Bacco, Manlio, Paolo Barsocchi, Erina Ferro, Alberto Gotta, and Massimiliano Ruggeri. 'The Digitisation of Agriculture: A Survey of Research Activities on Smart Farming'. *Array* 3–4 (1 September 2019): 100009. https://doi.org/10.1016/j.array.2019.100009.

Bach, Heike, and Wolfram Mauser. 'Sustainable Agriculture and Smart Farming'. In *Earth Observation - Open Science and Innovation*. ISSI Scientific Report 15, 2018.

Badia-Melis, R., P. Mishra, and L. Ruiz-García. 'Food Traceability: New Trends and Recent Advances. A Review'. *Food Control* 57 (1 November 2015): 393–401. https://doi.org/10.1016/j.foodcont.2015.05.005.

Bain & Company, Christopher Mitchell, Shivani Sehgal, Hemendra Mathur, and Priyanka Chopra. 'Indian Farming's Next Big Moment: Farming as a Service', 8 February 2018.

Banque Mondiale. 'Terres Arables (Hectares Par Personne, 1961 - 2016) | Données de La Banque Mondiale', 2020. https://donnees.banquemondiale.org/indicator/AG.LND.ARBL.HA.PC.

Barter, Paul. '"Cars Are Parked 95% of the Time". Let's Check!', 13 February 2013. https://www.reinventingparking.org/2013/02/cars-are-parked-95-of-time-lets-check.html.

Basso, Bruno, and John Antle. 'Digital Agriculture to Design Sustainable Agricultural Systems'. *Nature Sustainability* 3 (1 April 2020): 254–56. https://doi.org/10.1038/s41893-020-0510-0.

Bates, John, and David Leibling. 'Spaced Out - Perspectives on Parking Policy'. RAC Foundation, July 2012. https://www.racfoundation.org/research/mobility/spaced-out-perspectives-on-parking.

Bélanger, Gilles, and Andy Bootsma. 'Impacts des changements climatiques sur l'agriculture au Québec'. *65e Congrès de l'Ordre des agronomes du Québec*, 2016, 20.

Bélanger, Marie-Christine, and Yacine Bouroubi. 'Réflexion Sur l'état d'adoption Des Technologies d'agriculture de Précision Au Québec'. Centre de Référence en Agriculture et Agroalimentaire du Québec (CRAAQ), June 2015. https://www.agrireseau.net/documents/Document_90267.pdf.

Benke, Kurt, and Bruce Tomkins. 'Future Food-Production Systems: Vertical Farming and Controlled-Environment Agriculture'. *Sustainability: Science, Practice and Policy* 13 (1 January 2017): 13–26. https://doi.org/10.1080/15487733.2017.1394054.

Blockchain Technology Transforming the Agriculture and Food Supply Chain - Webinar, 2019. https://www.youtube.com/watch?v=aNf699UWnNw&feature=youtu.be.

Boudreau, Yvon, and Ministère de l'Agriculture, des Pêcheries et de l'Alimentation (MAPAQ). 'L'adoption des technologies de pointe en agriculture'. *BioClips*, 27 February 2018.

British Broadcasting Corporation (BBC). 'The Ageing Crisis Threatening Farming', 2019. http://www.bbc.com/future/bespoke/follow-the-food/the-ageing-crisis-threatening-farming/.

Charlebois, Sylvain, Anita Schwab, Raphael Henn, and Christian W. Huck. 'Food Fraud: An Exploratory Study for Measuring Consumer Perception towards Mislabeled Food Products and Influence on Self-Authentication Intentions'. *Trends in Food Science & Technology* 50 (1 April 2016): 211–18. https://doi.org/10.1016/j.tifs.2016.02.003.

Chui, Michael, James Manyika, Mehdi Miremadi, Nicolaus Henke, Rita Chung, Pieter Nel, Sankalp Malhotra, and McKinsey Global Institute. 'Notes from the AI Frontier: Applications and Value of Deep Learning | McKinsey'. McKinsey Global Institute, 17 April 2018.

https://www.mckinsey.com/featured-insights/artificial-intelligence/notes-from-the-ai-frontier-applications-and-value-of-deep-learning.

Comment Améliorer La Traçabilité de Nos Aliments ?, 2018. https://www.youtube.com/watch?v=79qdAutt-Fg&feature=youtu.be.

Connecting Food. 'Connecting Food - Food Transparency Blockchain'. Corporate, n.d. https://connecting-food.com/en/.

Dandage, K., R. Badia-Melis, and L. Ruiz-García. 'Indian Perspective in Food Traceability: A Review'. *Food Control* 71 (1 January 2017): 217–27. https://doi.org/10.1016/j.foodcont.2016.07.005.

De Marcellis-Warin, Nathalie, and Ingrid Peignier. 'Baromète CIRANO - Perception Des Risques Au Québec', 2018. https://barometre.cirano.qc.ca/.

Delmar Cengage Learning. 'Precision Agriculture - New Technologies, Tools, and Techniques', n.d. http://www.delmarlearning.com/companions/content/140188105X/trends/new_tech.asp.

Demartini, Melissa, Claudia Pinna, Flavio Tonelli, Sergio Terzi, Cinzia Sansone, and Chiara Testa. 'Food Industry Digitalization: From Challenges and Trends to Opportunities and Solutions'. *IFAC-PapersOnLine*, 16th IFAC Symposium on Information Control Problems in Manufacturing INCOM 2018, 51, no. 11 (1 January 2018): 1371–78. https://doi.org/10.1016/j.ifacol.2018.08.337.

Demestichas, Konstantinos, Nikolaos Peppes, Theodoros Alexakis, and Evgenia Adamopoulou. 'Blockchain in Agriculture Traceability Systems: A Review'. *Applied Sciences* 10, no. 12 (January 2020): 4113. https://doi.org/10.3390/app10124113.

Démonstration: semoir John Deere avec adaptation - Precision planting. Auxy, Loiret, France, 2017. https://www.youtube.com/watch?v=sYyzyKkNZWs&feature=youtu.be.

Devarakonda, Murthy, and Ching-Huei Tsou. 'Automated Problem List Generation from Electronic Medical Records in IBM Watson', 24 September 2014, 7.

Deveron. 'Precision Ag 101'. Deveron, n.d. http://deveronuas.com/learn-precision-agriculture-101/.

Dissanayake, Ravindra, and Thushan Amarasuriya. 'Role of Brand Identity in Developing Global Brands: A Literature Based Review on Case Comparison between Apple Iphone vs Samsung Smartphone Brands'. *Research Journal of Business Management-RJBM* Vol 2 (1 October 2015): 430–40. https://doi.org/10.17261/Pressacademia.2015312990.

Eisen, Joel B. 'Smart Regulation and Federalism for the Smart Grid'. *Harvard Environmental Law Review* 37 (2013): 1.

États membres de l'Union Européenne. 'A Smart and Sustainable Digitalfuture for European Agriculture and Rural Areas'. In *Shaping Europe's Digital Future - European Commission*. Commission Européenne - European Commission, 2019. https://ec.europa.eu/digital-single-market/en/news/eu-member-states-join-forces-digitalisation-european-agriculture-and-rural-areas.

Fédération de la relève agricole du Québec (FRAQ). 'Des Solutions Concrètes Pour La Pérennité Du Secteur Agricole', August 2011. http://www.fraq.qc.ca/wp-content/uploads/2014/02/memoire-fraq.pdf.

Felix, Ignacio, Adrian Martin, Vivek Mehta, Curt Mueller, and McKinsey & Company. 'US Food Supply Chain: Disruptions and Implications from COVID-19'. Corporate. McKinsey & Company, 2 July 2020. https://www.mckinsey.com/industries/consumer-packaged-goods/our-insights/us-food-supply-chain-disruptions-and-implications-from-covid-19.

Feng Tian. 'A Supply Chain Traceability System for Food Safety Based on HACCP, Blockchain Internet of Things'. In *2017 International Conference on Service Systems and Service Management*, 1–6, 2017. https://doi.org/10.1109/ICSSSM.2017.7996119.

Flores, Luis, Yoseline Sanchez, Edgar Ramos, Fernando Sotelo, and Nabeel Hamoud. 'Blockchain in Agribusiness Supply Chain Management: A Traceability Perspective'. In *Advances in Artificial Intelligence, Software and Systems Engineering*, edited by Tareq Ahram, 465–72. Advances in Intelligent Systems and Computing. Cham: Springer International Publishing, 2021. https://doi.org/10.1007/978-3-030-51328-3_64.

Fonds mondial pour la nature (WWF) - Canada. 'Péril dans les eaux canadiennes - Les flux environnementaux et l'avenir des ressources d'eau douce au Canada', 2009. http://awsassets.wwf.ca/downloads/wwf_canadas_riversatrisk_report_fr.pdf.

Fürnsinn, Stefan. 'Yara and IBM Launch an Open Collaboration for Farm and Field Data to Advance Sustainable Food Production'. Corporate. Yara International, 23 January 2020. https://www.yara.com/corporate-releases/yara-and-ibm-launch-an-open-collaboration-for-farm-and-field-data-to-advance-sustainable-food-production/.

Gerbet, Thomas, and Radio-Canada. 'Perte des terres agricoles au Québec : « C'est pire qu'avant »'. *Radio-Canada.ca*. 9 November 2018. https://ici.radio-canada.ca/nouvelle/1134484/agriculture-zonage-territoire-agricole-cptaq-loi-etalement-protection-accaparement.

Gibert, Chloé, and Antoine Bourdarias. 'Des drones arrivent dans les champs québécois'. *CScience IA* (blog), 6 October 2020. https://www.cscience.ca/2020/10/06/video-des-drones-arrivent-dans-les-champs-quebecois/.

Gouvernement du Canada, Innovation. 'Rapport des Tables de stratégies économiques du Canada : L'impératif de l'innovation et de la compétitivité - Tables sectorielles de stratégies économiques', 24 September 2018. https://www.ic.gc.ca/eic/site/098.nsf/fra/h_00020.html.

Gouvernement du Canada, and Innovation, Sciences et Développement économique Canada (ISDE). 'Nouveau projet de loi pour protéger la vie privée des Canadiens et accroître leur contrôle sur leurs données et leurs renseignements personnels'. Communiqués de presse, 17 November 2020. https://www.canada.ca/fr/innovation-sciences-developpement-economique/nouvelles/2020/11/nouveau-projet-de-loi-pour-proteger-la-vie-privee-des-canadiens-et-accroitre-leur-controle-sur-leurs-donnees-et-leurs-renseignements-personnels.html.

Greenman, Simon. 'The Secrets of Successful AI Startups. Who's Making Money in AI Part II?' *Towards Data Science* (blog), 15 April 2019. https://towardsdatascience.com/the-secrets-of-successful-ai-startups-whos-making-money-in-ai-part-ii-207fea92a8d5.

———. 'Who Is Going To Make Money In AI? Part I'. *Towards Data Science* (blog), 21 May 2018. https://towardsdatascience.com/who-is-going-to-make-money-in-ai-part-i-77a2f30b8cef.

Hoeren, Thomas, and Barbara Kolany-Raiser, eds. *Big Data in Context*. SpringerBriefs in Law. Springer International Publishing, 2018. https://doi.org/10.1007/978-3-319-62461-7.

Hutchinson, Asa. 'Governor Hutchinson, IBM Host Blockchain Technology Summit'. Politic. Arkansas Governor, 27 June 2018. https://governor.arkansas.gov/news-media/press-releases/governor-hutchinson-ibm-host-blockchain-technology-summit.

Imagia. 'Les dernières nouvelles au sujet de nos initiatives de recherche', 2020. https://imagia.com/fr/recherche/.

Intellias. 'How to Apply Blockchain for Supply Chain in Agriculture'. Corporate. *Intellias* (blog), 21 January 2020. https://www.intellias.com/how-to-apply-the-blockchain-to-agricultural-supply-chains-while-avoiding-embarrassing-mistakes/.

International Federation of Robotics (IFR). 'The Impact of Robots on Productivity, Employment and Jobs'. Frankfurt, Germany: International Federation of Robotics (IFR), April 2017. https://ifr.org/downloads/papers/IFR_The_Impact_of_Robots_on_Employment_Positioning_Paper.pdf.

John Deere. *John Deere AutoTrac Sprayer Guidance Systems Video*, 2016. https://www.youtube.com/watch?v=T03MxU_R2P0&feature=youtu.be.

Julien, Sarah-Sophie, Daniel Richard, Direction des études économiques et d'appui aux filières, Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ), Guillaume Couture, Julie Labrecque, Jean-Marie Labrecque, Luc Pelletier, and Commission sur l'avenir de l'agriculture et de l'agroalimentaire québécois (CAAAQ). *Monographie de l'industrie acéricole au Québec*, 2006.

Kaiser, Harry M., Susan J. Riha, Daniel S. Wilks, David G. Rossiter, and Radha Sampath. 'A Farm-Level Analysis of Economic and Agronomic Impacts of Gradual Climate Warming'. *American Journal of Agricultural Economics* 75, no. 2 (1993): 387–98. https://doi.org/10.2307/1242923.

Kamilaris, Andreas, Agusti Fonts, and Francesc X. Prenafeta-Boldú. 'The Rise of Blockchain Technology in Agriculture and Food Supply Chains'. *Trends in Food Science & Technology* 91 (1 September 2019): 640–52. https://doi.org/10.1016/j.tifs.2019.07.034.

Kencee | Localisation en temps réel. 'Kencee U2 - L'outil de distanciation sociale pour vos employés', 2020. https://kenceertls.com/kencee-u2/.

Kesri, Karim, and Ministère de l'Agriculture, des Pêcheries et de l'Alimentation (MAPAQ). 'Les exportations bioalimentaires internationales du Québec'. *BioClips+*, December 2012.

Kosior, Katarzyna. ‘Digital Transformation in the Agri-Food Sector – Opportunities and Challenges’. *Polish Association of Agricultural Economists and Agribusiness - Stowarzyszenie Ekonomistow Rolnictwa e Agrobiznesu (SERiA)*, Roczniki (Annals), 2018, no. 2 (7 May 2018). https://doi.org/10.22004/ag.econ.293647, 10.5604/01.3001.0011.8122.

Kruppa, Miles. ‘Venture Capital Floods into Food-Tech’. *Financial Times*, 23 September 2020. https://www.ft.com/content/849393e2-b14f-43b6-966d-88fdf9d110ab.

La Robotique et Technologies de l’agriculture de Précision Ont Changé Le Travail à Notre Ferme, 2018. https://www.youtube.com/watch?v=cSRwq1SKG3Q&feature=youtu.be.

Leflaive, Xavier, Maria Witmer, Roberto Martin-Hurtado, Marloes Bakker, Tom Kram, Lex Bouwman, Hans Visser, et al. ‘Perspectives de l’environnement de l’OCDE à l’horizon 2050 - Les Conséquences de l’inaction - Chapitre 5 : Eau’. Organisation de coopération et de développement économiques (OCDE), 2012. http://www.oecd.org/fr/env/indicateurs-modelisation-perspectives/49848948.pdf.

Lemay, Mathieu, and Digital Ubiquity Capital. ‘État de la connectivité des terres agricoles au Québec’, 10 November 2020. https://www.digitalubiquitycapital.com/about/.

Lenniy, Dmytro, Artem Zagorulko, and Intellias. ‘Sustainable Agriculture: From Tech Solutions to Ecosystem’. Whitepaper, August 2020. https://www.intellias.com/download-file/sustainable-agriculture-whitepaper.pdf.

Lescop, Denis, and Elena Lescop. ‘Platform-Based Ecosystem and Firm/Market Equivalency: The Case of Apple Iphone’. *Understanding Business Ecosystems: How Firms Succeed in a New World of Convergence*, 2013.

Letaifa, Soumaya Ben, Anne Gratacap, and Thierry Isckia. *Understanding Business Ecosystems: How Firms Succeed in the New World of Convergence?* De Boeck Superieur, 2013.

Lund, Susan, James Manyika, Jonathan Woetzel, Edward Barriball, Mekala Krishnan, Kurt Alicke, Michael Birshan, et al. ‘Risk, Resilience, and Rebalancing in Global Value Chains’, 6 August 2020. https://view.ceros.com/mckinsey/autocx-ex2-v1-online-2-2-2-2-2-2-3-1-2-1-2-4-2-1-2.

Maddox, Teena. ‘Agriculture 4.0 : How Digital Farming Is Revolutionizing the Future of Food’. *TechRepublic*, 12 December 2018. https://www.techrepublic.com/article/agriculture-4-0-how-digital-farming-is-revolutionizing-the-future-of-food/.

Mahdu, Omchand. ‘The Impacts of Climate Change on Rice Production and Small Farmers’ Adaptation: A Case of Guyana’, 22 April 2019. https://vtechworks.lib.vt.edu/handle/10919/89087.

Masters, Kiri. ‘89% Of Consumers Are More Likely To Buy Products From Amazon Than Other E-Commerce Sites: Study’. *Forbes*, 20 March 2019. https://www.forbes.com/sites/kirimasters/2019/03/20/study-89-of-consumers-are-more-likely-to-buy-products-from-amazon-than-other-e-commerce-sites/.

Milman, Oliver. ‘Earth Has Lost a Third of Arable Land in Past 40 Years, Scientists Say’. *The Guardian*, 2 December 2015, sec. Environment.

https://www.theguardian.com/environment/2015/dec/02/arable-land-soil-food-security-shortage.

Ministère de l'Agriculture, des Pêcheries et de l'Alimentation (MAPAQ). 'L'industrie bioalimentaire québécoise résiliente en 2018'. *BioClips*, 21 May 2019.

Mirabelli, Giovanni, and Vittorio Solina. 'Blockchain and Agricultural Supply Chains Traceability: Research Trends and Future Challenges'. *Procedia Manufacturing*, International Conference on Industry 4.0 and Smart Manufacturing (ISM 2019), 42 (1 January 2020): 414–21. https://doi.org/10.1016/j.promfg.2020.02.054.

Montet, Virginie. 'Après Les Livres, Le Streaming et l'épicerie, Amazon Cible La Pharmacie'. *Agence France Press*, 17 November 2020. https://www.lapresse.ca/affaires/entreprises/2020-11-17/apres-les-livres-le-streaming-et-l-epicerie-amazon-cible-la-pharmacie.php.

Mulla, David, and Raj Khosla. 'Historical Evolution and Recent Advances in Precision Farming'. In *Soil-Specific Farming*, edited by Rattan Lal and B Stewart, 1–36. Advances in Soil Science. CRC Press, 2015. https://doi.org/10.1201/b18759-2.

Organisation de coopération et de développement économiques (OCDE). 'Food Supply Chains and COVID-19: Impacts and Policy Lessons', 2 June 2020. http://www.oecd.org/coronavirus/policy-responses/food-supply-chains-and-covid-19-impacts-and-policy-lessons-71b57aea/.

Organisation des Nations Unies (ONU). 'Questions thématiques - La population', 14 December 2015. https://www.un.org/fr/sections/issues-depth/population/index.html.

Paredes, Miguel. 'Can Artificial Intelligence Help Reduce Human Medical Errors? Two Examples from ICUs in the US and Peru'. *Tech Policy Institute*, 19 February 2018, 12.

Patates Dolbec. *Patates Dolbec :: tout voir de A à Z!*, 2018. https://www.youtube.com/watch?v=7Yd4_kNtU_8.

Pesapane, Filippo, Marina Codari, and Francesco Sardanelli. 'Artificial Intelligence in Medical Imaging: Threat or Opportunity? Radiologists Again at the Forefront of Innovation in Medicine'. *European Radiology Experimental* 2, no. 1 (24 October 2018): 35. https://doi.org/10.1186/s41747-018-0061-6.

Petrillo, Antonella, Fabio De Felice, Raffaele Cioffi, and Federico Zomparelli. 'Fourth Industrial Revolution: Current Practices, Challenges, and Opportunities'. *Digital Transformation in Smart Manufacturing*, 28 February 2018. https://doi.org/10.5772/intechopen.72304.

Praveen, Bushra, and Pritee Sharma. 'Climate Change and Its Impacts on Indian Agriculture: An Econometric Analysis'. *Journal of Public Affairs* 20, no. 1 (2020): e1972. https://doi.org/10.1002/pa.1972.

Producteurs et productrices acéricoles du Québec (PPAQ). 'Statistiques acéricoles 2019 - 30 ans déjà, plan conjoint'. Producteurs et productrices acéricoles du Québec (PPAQ), 2019. https://ppaq.ca/app/uploads/2020/10/Dossier_economique-Statistiques_2019.pdf.

Pulvérisateur modifié: l'agriculture de précision à sa plus simple expression selon M. Paul Caplette, 2020. https://www.youtube.com/watch?v=Ng3I8d-UXNg&feature=youtu.be.

Radio-Canada. 'Le manque de relève agricole, un défi de taille pour les futurs agronomes'. *Radio-Canada.ca*. 14 January 2017. https://ici.radio-canada.ca/nouvelle/1010902/releve-agricole-agronomes-quebec.

Rigg, Jonathan, Monchai Phongsiri, Buapun Promphakping, Albert Salamanca, and Mattara Sripun. 'Who Will Tend the Farm? Interrogating the Ageing Asian Farmer'. *The Journal of Peasant Studies* 47, no. 2 (23 February 2020): 306–25. https://doi.org/10.1080/03066150.2019.1572605.

Rousseau, Henri-Paul, and Centre interuniversitaire de recherche en analyse des organisations (CIRANO). 'Le panier bleu : un outil pour accélérer la transition numérique et écologique du Québec'. Rapport Bourgogne, ISSN 1701-9990. Centre interuniversitaire de recherche en analyse des organisations (CIRANO), 2020. https://www.cirano.qc.ca/fr/sommaires/2020RB-06.

Royer, Annie, Nathalie De Marcellis-Warin, Ingrid Peignier, Christophe Mondin, Molivann Panot, and Centre interuniversitaire de recherche en analyse des organisations (CIRANO). 'Gouvernance des données au sein de l'industrie laitière québécoise : perceptions et enjeux'. Rapport de projet, ISSN 1499-8629. Centre interuniversitaire de recherche en analyse des organisations (CIRANO), 2020. https://cirano.qc.ca/fr/sommaires/2020RP-06.

Royer, Annie, Nathalie De Marcellis-Warin, Ingrid Peignier, Thierry Warin, Christophe Mondin, Molivann Panot, and Centre interuniversitaire de recherche en analyse des organisations (CIRANO). 'Les enjeux du numérique dans le secteur agricole - Défis et opportunités - CIRANO'. Rapport de projet, ISSN 1499-8629. Centre interuniversitaire de recherche en analyse des organisations (CIRANO), 2020. https://cirano.qc.ca/fr/sommaires/2020RP-12.

Saiz-Rubio, Verónica, and Francisco Rovira-Más. 'From Smart Farming towards Agriculture 5.0: A Review on Crop Data Management'. *Agronomy* 10, no. 2 (February 2020): 207. https://doi.org/10.3390/agronomy10020207.

Sandler, Rachel. 'How the IPhone Changed the Telecommunications Industry'. *USA Today*, 4 July 2017. https://www.usatoday.com/story/tech/news/2017/07/04/how-iphone-changed-telecommunications-industry/103154146/.

Sargeant, Richard. 'AI Safety: Correcting 200,000 Years of Human Error'. *Faculty* (blog), 26 August 2019. https://faculty.ai/blog/ai-safety-correcting-200000-years-of-human-error/.

Schönfeld, Max v., and Laura Bittner. 'Big Data on a Farm—Smart Farming'. In *Big Data in Context*, 2018. https://doi.org/10.1007/978-3-319-62461-7.

Soon, J. M., S. C. Krzyzaniak, Z. Shuttlewood, M. Smith, and L. Jack. 'Food Fraud Vulnerability Assessment Tools Used in Food Industry'. *Food Control* 101 (1 July 2019): 225–32. https://doi.org/10.1016/j.foodcont.2019.03.002.

StartUs Insights. ‘8 Blockchain Startups Disrupting The Agricultural Industry’. *StartUs Insights* (blog), 19 December 2018. https://www.startus-insights.com/innovators-guide/8-blockchain-startups-disrupting-the-agricultural-industry/.

Statcounter GlobalStats. ‘Search Engine Market Share Worldwide - October 2020’. StatCounter Global Stats, October 2020. https://gs.statcounter.com/search-engine-market-share.

Strain, Mike. ‘Better Buy: Shopify vs. Amazon’. *The Motley Fool* (blog), 27 September 2020. https://www.fool.com/investing/2020/09/27/better-buy-shopify-vs-amazon/.

Sylvester, Gerard, International Telecommunication Union, and Food and Agriculture Organization of the United Nations (FAO). *E-Agriculture in Action — Blockchain for Agriculture : Opportunities and Challenges*, 2019.

Thompson, Ben. ‘Defining Aggregators’. *Stratechery by Ben Thompson* (blog), 26 September 2017. https://stratechery.com/2017/defining-aggregators/.

———. ‘Is the Internet Different?’ *Stratechery by Ben Thompson* (blog), 3 November 2020. https://stratechery.com/2020/is-the-internet-different/.

———. ‘Shopify and the Power of Platforms’. *Stratechery by Ben Thompson* (blog), 11 July 2019. https://stratechery.com/2019/shopify-and-the-power-of-platforms/.

———. ‘The Moat Map’. *Stratechery by Ben Thompson* (blog), 15 May 2018. https://stratechery.com/2018/the-moat-map/.

Tibola, Casiane Salete, Simone Alves de Silva, Alvaro Augusto Dossa, and Diego Inácio Patrício. ‘Economically Motivated Food Fraud and Adulteration in Brazil: Incidents and Alternatives to Minimize Occurrence’. *Journal of Food Science* 83, no. 8 (18 July 2018). https://onlinelibrary.wiley.com/doi/full/10.1111/1750-3841.14279.

Tremblay, Diane. ‘Agriculture: Un Robot d’ici Bientôt Prêt à Prendre La Relève’. *Le Journal de Québec*, 18 October 2020. https://www.journaldequebec.com/2020/10/18/un-robot-dici-bientot-pret-a-prendre-la-releve.

Union des producteurs agricoles (UPA), and ÉcoRessources. ‘L’agriculture Au Québec, Un Potentiel de Développement à Exploiter - Évaluation Du Potentiel de Croissance 2016-2025 En Agriculture et de l’effet de Cette Croissance Sur Les Retombées Conomiques Du Secteur’, February 2017. https://www.upa.qc.ca/wp-content/uploads/filebase/fr/memoires/UPA_Rapport-croissance_Final-ecoressources-2017-02-08.pdf.

Union Européenne (UE). ‘Déclaration de Cork 2.0 - Pour une vie meilleure en milieu rural’, 12. Cork, Irlande: Luxembourg: Office des publications de l’Union européenne, 2016, 2016. https://doi.org/doi:10.2762/839519.

Utkin, Michael, and eFarmer B.V. ‘Farming as a Service (FaaS) - New Business Model in Agriculture’. 28 June 2018.

Vanlauwe, B., J. Six, N. Sanginga, and A. A. Adesina. 'Soil Fertility Decline at the Base of Rural Poverty in Sub-Saharan Africa'. *Nature Plants* 1, no. 7 (7 July 2015): 1–1. https://doi.org/10.1038/nplants.2015.101.

West, Darrell M., John R. Allen, and The Brookings Institution. 'How Artificial Intelligence Is Transforming the World', 24 April 2018. https://www.brookings.edu/research/how-artificial-intelligence-is-transforming-the-world/.

When Food Meets Blockchain. Visioconference, n.d. https://www.youtube.com/watch?v=Yy2b2VBsrag.

Wolfert, Sjaak, Lan Ge, Cor Verdouw, and M.J. Bogaardt. 'Big Data in Smart Farming – A Review'. *Agricultural Systems* 153 (1 May 2017): 69–80. https://doi.org/10.1016/j.agsy.2017.01.023.

Wood, Sylvia L. R., Jeanine M. Rhemtulla, and Oliver T. Coomes. 'Cropping History Trumps Fallow Duration in Long-Term Soil and Vegetation Dynamics of Shifting Cultivation Systems'. *Ecological Applications* 27, no. 2 (2017): 519–31. https://doi.org/10.1002/eap.1462.

Wu, Tim. 'Reviewing Ben Thompson's Stratechery'. *Superwuster Medium* (blog), 11 November 2020. https://superwuster.medium.com/reviewing-ben-thompsons-stratechery-45b545dd959.

Zetzsche, Dirk A., Ross P. Buckley, Janos N. Barberis, and Douglas W. Arner. 'Regulating a Revolution: From Regulatory Sandboxes to Smart Regulation'. *Fordham Journal of Corporate and Financial Law* 23 (2018 2017): 31.

Zhang, Qin, and Hermann Auernhammer. *Precision Agriculture Technology for Crop Farming*, 2016.

Appendix – State of Agricultural Land Connectivity in Quebec Report

by Mathieu Lemay and Digital Ubiquity Capital, November 10, 2020

State of Farmland Connectivity in Quebec
Information Summary

Mathieu Lemay
November 10, 2020

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DIGITAL UBIQUITY CAPITAL

Digital Ubiquity Capital provides differentiated investment solutions, including partnerships with leading national and global investors, aimed at bridging the digital divide in Canada's regions.

Our intelligent platforms and replicable structures draw on global best practices to evaluate connectivity projects, isolate risk and share value while ensuring the expected return on investment.

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Content

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Methodology

This summary study was produced using the following data sources:

- Industry Canada's national broadband database (National Broadband Data)
- *Parcels and Reported Agricultural Productions Database* (BDPPAD)
- Empirical measures of CIRA (Internet Performance Test) compiled by currently connected Internet users in Canada.

These data, once aggregated, made it possible to infer certain general statistics regarding, on the one hand, the availability or unavailability of connectivity for parcels of agricultural land in Quebec and, on the other hand, the speed of such connectivity if it exists.

These data do not, however, make it possible to accurately identify the nature and type of farming operations or the exact number of farms served or not served by connectivity.

We would be pleased to provide additional information if required.

[Signature]
Mathieu Lemay
Chief Strategy Officer and Cofounder

Highlights

Connectivity criteria established in Canada by the CRTC require a minimum download speed of 25 Mbps (upload) and a minimum upload speed of 5 Mbps (download) for wireless services. For wireline infrastructures, the minimum capacity must be 50 Mbps download and 10 Mbps upload.

Given that agricultural parcels are generally served in Quebec by connectivity networks using wireless technology, we will use the criteria of 25 Mbps download (upload) and 5 Mbps upload (download) as reference objectives.

Taking into consideration these criteria and the data collected from the data sources listed above, we can conclude that approximately $23.4 of farmland in unserved or underserved areas in terms of connectivity does not meet the minimum criteria set by the CRTC.

We can also conclude that while 76.6% of the farmland is located in areas considered well served under the CRTC criteria, the more accurate empirical data from the connectivity tests allow us to conclude that 68.3% of these farms receive service below the minimum 25 Mbps criterion.

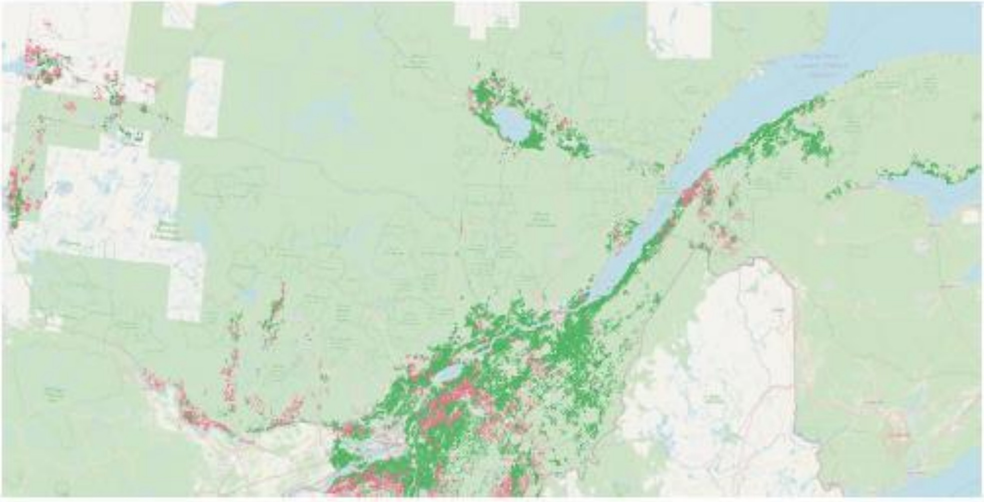
As indicated by the CRTC, the minimum connectivity level of 25 Mbps, while adequate to allow citizens to access their e-mail and organize video conferencing sessions in a limited way, is not sufficient to allow access to new technologies in precision agriculture, especially applications requiring a cloud-computing platform that has now become the standard in the agricultural world.

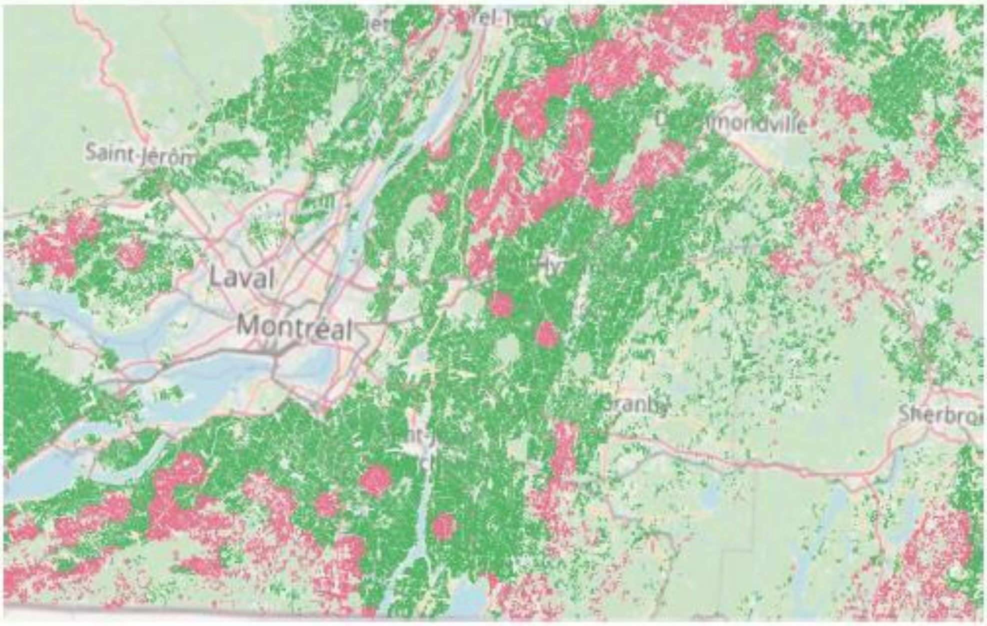
In the end, we can conclude that based on empirical data from agricultural plots located in unserved or underserved areas, 93.3% of the tests do not meet the minimum 25 Mbps download speed. In this respect, it is important to point out a second issue: technological applications in the agricultural field increasingly require “symmetrical” download and upload capacity, i.e. where download and upload speeds should be similar. As an example, this symmetry has become essential for applications that allow, among other things, the analysis of data by third parties (customers, suppliers, subcontractors, etc.), teleconferences, the exchange of large technical documentation and, finally, the transmission of information collected for real-time verification purposes.

Maps and Data

The green areas represent served agricultural plots with a minimum of 25 Mbps/5 Mbps while the red areas represent unserved or underserved agricultural plots.

Precise statistics regarding the presence or not of connectivity for each of the regions and sub-regions of Quebec as well as the quality of this connectivity, if it exists, are available and can be provided upon request.





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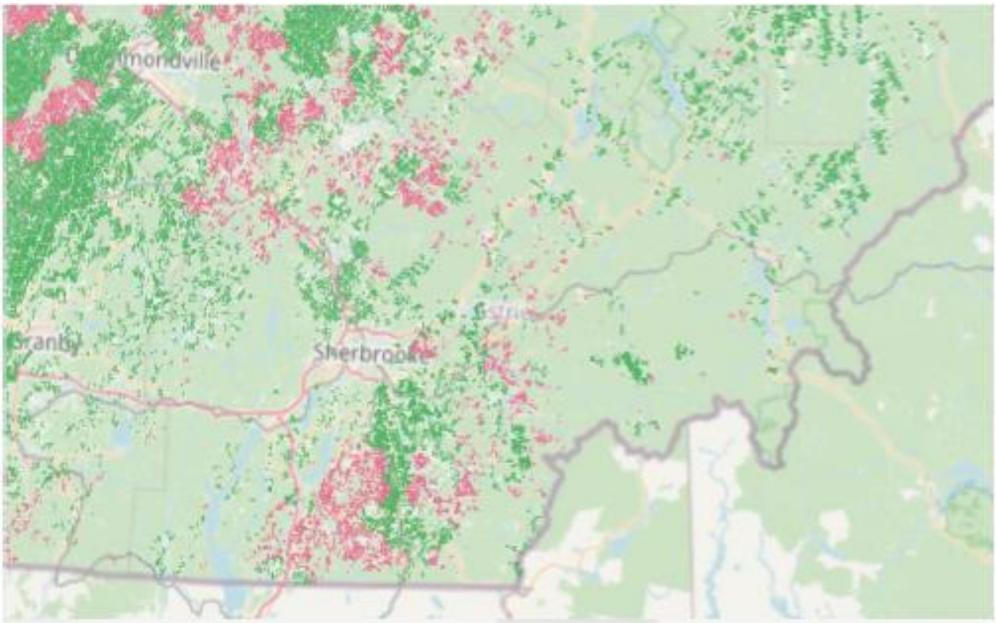

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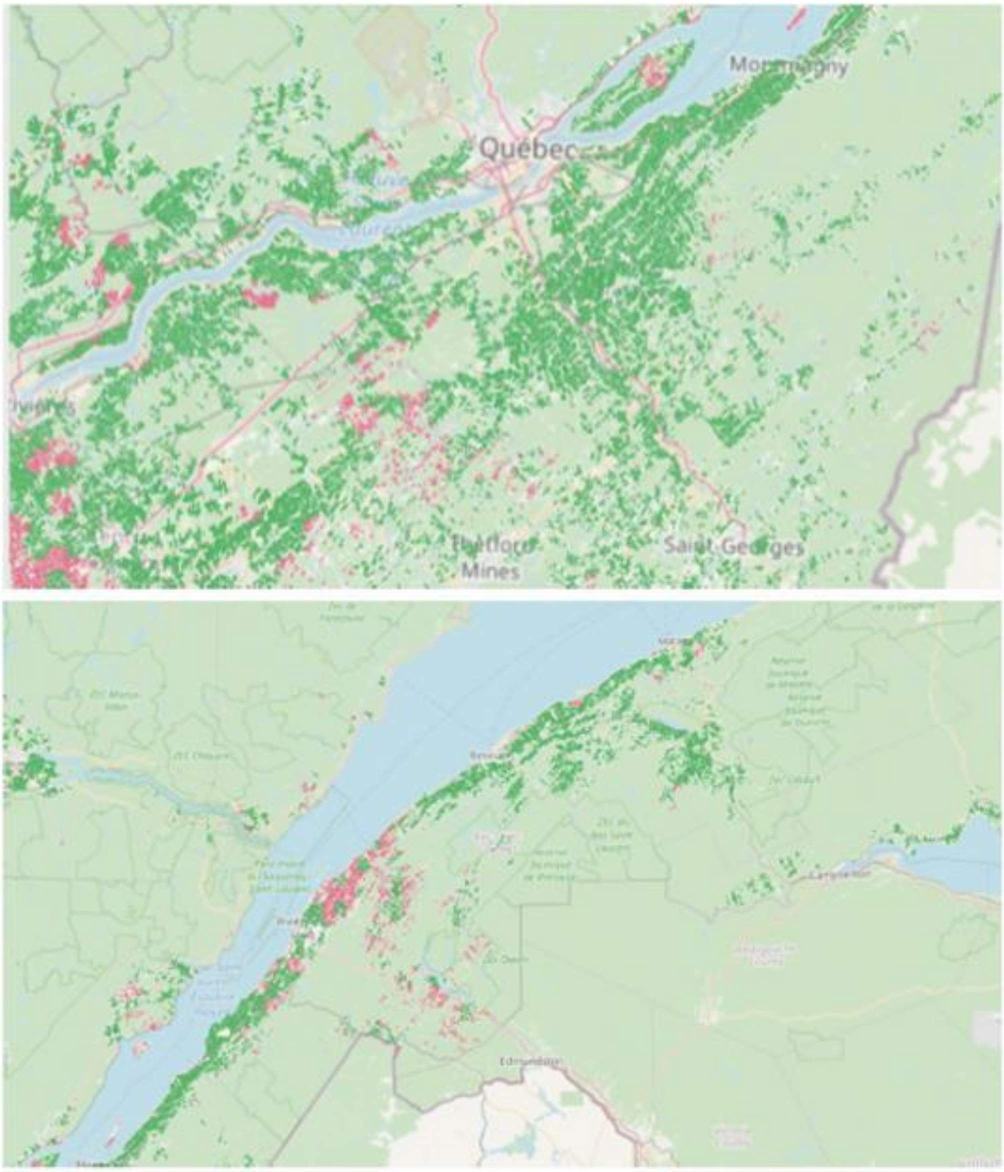

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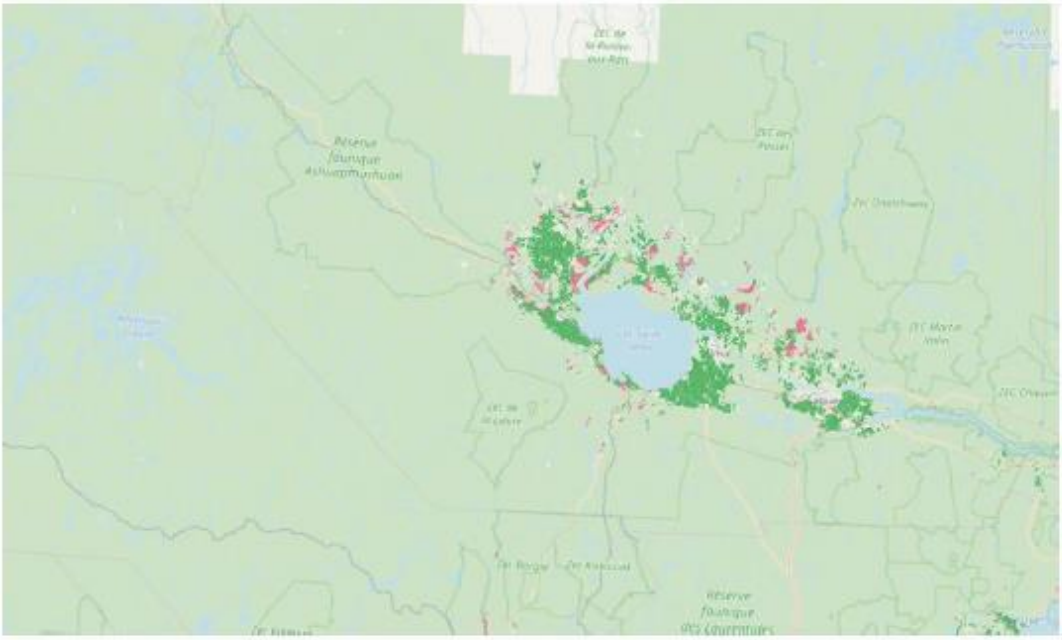

Conclusion and General Findings

Although preliminary and cursory, the general findings in this report allow us to conclude beyond any doubt that the poor access to and quality of connectivity for agricultural parcels located in Quebec does not meet the minimum criteria set by the CRTC.

The problem of access to quality connectivity significantly limits farmers' ability to deal with the technological changes that are accelerating in their industry and directly affects their ability to create the value essential to maintaining and developing their activities.

The problem of access to quality connectivity is particularly true for regions located in Abitibi, the northern Outaouais and areas bordering the US border. A granular analysis of the available data could be useful to guide any national strategy more accurately in this regard.

End of Report

Mathieu Lemay