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IoT in agriculture: How to improve efficiency in agricultural production with IoT technology

May 2023

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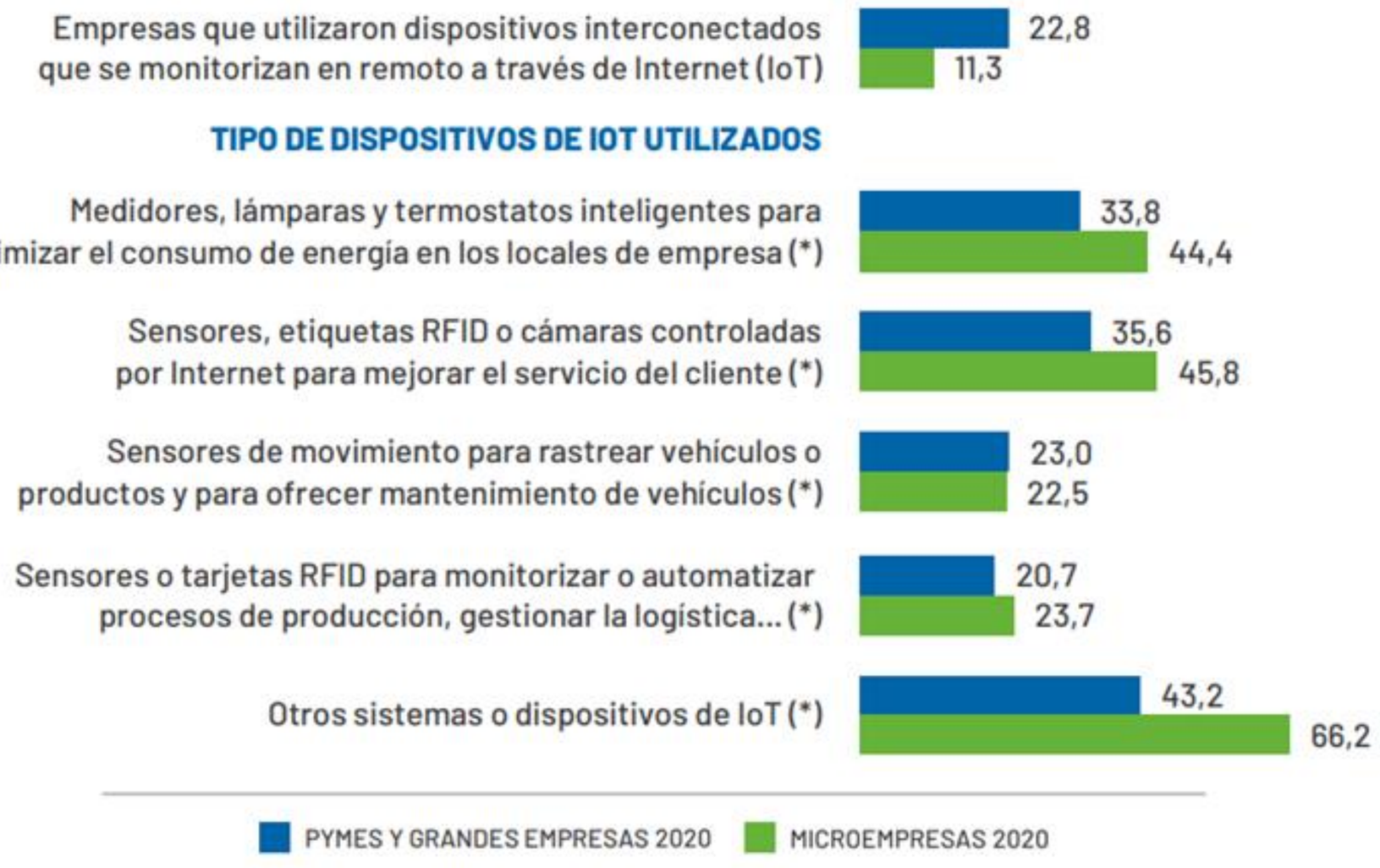
1. Introduction

IoT (Internet of Things) technology has revolutionised the way we interact with the world and has enabled the connection of devices in our everyday lives. From household appliances to vehicles, IoT is present in multiple areas of our lives. The IoT allows us to remotely connect and control devices in our daily lives, collecting real-time data and automating tasks in a variety of environments.

This technology is becoming increasingly relevant, as shown by data from ONTSI's most recent SME Digitalisation Report 2021, which indicates that, in 2020, 22.8% of companies with 10 or more employees and 11.3% of companies with fewer than 10 employees implemented IoT devices.. [REF-01]

GRÁFICO 13. EMPRESAS QUE UTILIZARON DISPOSITIVOS IOT Y TIPO DE DISPOSITIVOS IOT UTILIZADOS

Fuente: ONTSI, a partir de datos INE 2020.
Base: Total de empresas del sector.
(*) Porcentaje sobre total de empresas que utilizan algún dispositivo IoT.



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In this regard, IDC, one of the world's leading providers of market intelligence for the ICT sector predicts that **"spending in Spain on IoT will remain stable at 13.1% CAGR in 2026."[REF-02]** They also indicate that "steady double-digit growth in IoT spending is expected through 2026, with faster growth in investments related to advanced payments and purchasing and electric vehicle charging." [REF-03]

The **agricultural sector** is currently **facing a series of challenges [REF-04]** that **threaten the sustainability and profitability of food production**. These challenges include **water scarcity or drought** in Spanish fields, climate variability, **diminishing natural resources**, competitive pressures, labour shortages and increasing consumer demand for healthier and safer food. In this context, it is **important** to explore the **potential of IoT technology in the agricultural sector**, in particular for **agricultural SMEs and self-employed farmers** who can benefit from **cost-effective and easy-to-implement technological solutions. [REF-05]**

IoT technology, with its ability to **collect, analyse and transmit data in real time,** has become **a key tool** in addressing these **challenges**. In the agricultural sector, IoT is being used to **improve process efficiency, reduce costs, increase productivity and ensure food safety and quality**.

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Agriculture is a **fundamental sector in the economy of many countries,** including **Spain.** According to data from the Ministry of Agriculture, Fisheries and Food, "the Agri-Food System generated a GVA of €108,352 million in 2020. This figure represents 10.6% of the total GVA of the Spanish economy or 9.7% in terms of Gross Domestic Product (GDP). **[REF-06]** Therefore, any improvement in the efficiency and productivity of agriculture has a direct impact on the economy and the well-being of society in general. In this sense, **IoT technology** has positioned itself as a **key tool for optimising agricultural processes and maximising crop yields.**

It is essential that companies in the sector look for ways to optimise their processes as they face **a variety of challenges** on a daily basis:

- The **unpredictable nature** of physical conditions, effects of climate change, and market evolutions are variables beyond the reach of agricultural entrepreneurs.
- The **profitability of farming operations** is constantly compromised, with dependencies on uncontrollable factors.
- **IoT technologies can bring value to the agricultural sector** by automating both data collection and subsequent analysis to optimise production.
- **Agricultural production** depends on a large number of different factors such as chemical, environmental, meteorological, economic, etc.
- **Having up-to-date and accurate information** about them will allow producers to analyse the state of their operations and make appropriate decisions.

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- Operational processes in the Agro sector consume large amounts of energy, however, there are inputs that can be reduced thanks to IoT technology:

I. Water pumping
II. Heat for food processing
III. Cold chain & storage
IV. Machinery
V. Fertilisers
VI. Transport & distribution
VII. Processing (“Beyond the farm gate”)

2. Description of IoT techonology

IoT technology has been applied in various sectors such **as industry, transport and energy**, among others. Examples of IoT applications in these sectors include real-time **monitoring of machinery, optimisation of transport routes and efficient management of energy consumption.**

In an article by McKinsey, they define IoT (Internet of Things) technology as describing "physical objects equipped with sensors and actuators that communicate with computer systems over wired or wireless networks, allowing them to monitor or even digitally control the physical world." **[REF-07] SAP**, as its website states, is one of the **"world's leading producers of business process management software", [REF-08]** and **defines the four phases of IoT operation in a simple way: [REF-09]**

Four key stages in the internet of things

1. First, **data must be captured using sensors** that collect information from the agricultural environment, such as temperature, humidity, soil quality and more.
2. Once the data is captured, it **must be shared through available network connections**, sent to a public or private cloud platform, to another IoT device, or stored locally for further processing.

3. Once the **data has been collected and shared**, it is p**rocessed**. At this point, specific software is used to analyse the information collected and make decisions based on the results obtained.
4. Finally, the **processed data is acted upon**, analysing the information accumulated from all the IoT devices in the network. In this way, valuable insights can be gained to enable more accurate and confident measurements and business decisions in the agricultural sector.

IoT communication is based on **connecting devices over a network to collect, transmit and process data in real time.** In the context of agriculture, connected devices can **include soil, climate, humidity, temperature sensors,** drones or even **agricultural machinery**. These devices **generate data that is collected and transmitted over a network,** such as the internet or a local network, for processing and analysis.
In the agricultural sector, IoT technology can also be applied in a variety of ways, such as crop **monitoring and smart irrigation management**, and even a few more use cases that will be detailed later.

3. Benefits of implementing IoT technology in agriculture

As indicated above, the use of IoT technology in agriculture provides **numerous benefits** for farmers and producers. Some **specific examples of these benefits** are detailed below:

1. **Real-time monitoring:** IoT sensors and devices can monitor crop and environmental conditions in real time, allowing farmers to make informed crop management decisions and reduce the risk of losses. For example, sensors can measure soil moisture and temperature, allowing farmers to adjust irrigation and ventilation to ensure optimal conditions for plant growth.
2. **Optimising resource use:** IoT can help farmers optimise the use of resources, such as water and fertiliser, which can improve efficiency and reduce costs. For example, sensors can detect soil moisture and automatically adjust irrigation to avoid wasting water.
3. **Improved product quality:** Real-time monitoring and resource optimisation can help farmers improve the quality of the products they produce. For example, the use of sensors can ensure that temperature and humidity conditions are optimal for storage and transport of fresh produce, which can reduce losses and improve product quality.

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4. **Increased productivity:** The use of IoT in agriculture can increase productivity by enabling farmers to work more efficiently. For example, sensors can monitor crop growth and send alerts in case of pests or diseases, allowing the farmer to take preventive measures before significant losses occur.
5. **Cost reduction:** IoT can help farmers reduce costs by optimising the use of resources and improving efficiency. Sensors can detect the level of humidity and temperature in storage facilities, allowing farmers to adjust ventilation and indoor climate to maintain the quality of fresh produce, thereby reducing food waste and energy costs, and consequently reducing expenses.
6. **Improved safety for farmers:** IoT can help improve farmers' safety by allowing them to monitor environmental conditions and avoid safety risks. For example, sensors can detect the presence of toxic gases in the surrounding area and alert farmers to take safety measures before entering the area.
7. **Improving sustainability:** The use of IoT in agriculture can improve sustainability by reducing resource waste and environmental impact. For example, sensors can monitor water and fertiliser use and optimise their use, thereby reducing waste and environmental impact.

4.IoT use cases for agriculture

IoT technology has had a **major impact on agriculture**, enabling farmers and producers to **optimise their processes, improve efficiency and increase production.** In this section, we describe some **IoT use cases in agriculture** that are particularly relevant for small and medium-sized enterprises, as well as for the self-employed looking to improve their profitability and sustainability. Some of the **main applications of IoT in agriculture are:**

1. **Monitoring weather and soil conditions:**

IoT allows farmers to collect data on weather and soil conditions more accurately and in real time.

With the help of specific sensors, such as temperature sensors, humidity sensors, anemometers, rain gauges, etc., farmers **can collect data on temperature, humidity, wind speed and rainfall, as well as information on soil quality, such as pH and nutrient concentration.**

This data can be collected continuously and transmitted over the network to be analysed and visualised on an online platform. Farmers can then **use this information** to **adjust their cultivation practices,** such as the amount of water applied to the crop, the frequency of irrigation, and the amount and type of fertilisers used.

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All of this can **improve productivity and reduce costs**. In addition, real-time monitoring can also **help prevent crop loss due to extreme weather conditions or natural disasters**, allowing farmers to take **protective measures** before irreparable damage occurs.

A concrete example of how IoT technology can improve efficiency in agriculture is the case of **Frutas Mifra,** which has **implemented a smart irrigation solution** developed by Telefónica Tech and Shepard. Thanks to this technology, farmers can **control the irrigation of their crops in real time and from anywhere**, adjusting irrigation according to the needs of each plant and the state of the crop. Thanks to this, they have "**achieved savings of 25% in fertilisers and 30% in water and a great optimisation of the time spent** on tasks on the farm itself". **[REF-10]**

2. Soil moisture and air quality monitoring

For this use case, **soil moisture sensors and thermometers** are used, which are **connected to a wireless sensor network**. There are different types of soil moisture sensors, but the most common ones use capacitance or electrical resistance to **measure moisture**. **Capacitive sensors measure the amount of water** in the soil **by measuring the electrical capacitance of the soil**, while resistance **sensors measure moisture** by measuring the electrical resistance of the soil.

Sensors **can be placed at different depths in the soil**, depending on the depth of the plant roots and the irrigation strategy used. In addition, some sensors can also measure **soil temperature**, which is useful for monitoring plant growth.

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The information collected is sent to an **application**, which uses this knowledge to **adjust irrigation and plant ventilation**. Farmers can set **specific moisture thresholds** and **program automated irrigation systems** to activate when certain soil moisture levels are reached. This data can also be **used for planting and fertilisation planning**, resulting in more optimised yields.

These would be some examples of humidity sensors:

An **air quality sensor** can also be used to measure the **concentration of carbon dioxide (CO2)** in the greenhouse atmosphere and other parameters to help growers adjust ventilation and lighting to ensure that plants receive the right amount of CO2 and sunlight, which can also improve crop quality and yield.

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Some examples of air quality sensors from different suppliers that can be easily found on the Internet and on popular marketplaces:

- Carbon dioxide (CO2) sensor: CO2 sensors measure the concentration of carbon dioxide in the air. These sensors are important because plants need carbon dioxide for photosynthesis and growth. An example of a CO2 sensor is the CO2Meter RAD-0501 sensor.
- Nitrogen oxide (NOx) sensor: NOx sensors measure the concentration of nitrogen oxide in the air. NOx can be harmful to plant health and can reduce air quality. An example of a NOx sensor is the Aeroqual Series 500 sensor.
- Ammonia (NH3) sensor: NH3 sensors measure the concentration of ammonia in the air. Ammonia can be harmful to plants and can reduce air quality. An example of an NH3 sensor is the ECOTECH Serinus 51 sensor.
- Ozone (O3) sensor: O3 sensors measure the concentration of ozone in the air. Ozone can be detrimental to plant health and can reduce air quality. An example of an O3 sensor is the Aeroqual Series 500 sensor.

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The use of sensors in sustainable agriculture **can help farmers make informed decisions on resource use and improve the efficiency and profitability of their crops**. In addition, by **optimising the use of water and fertilisers**, the environmental impacts of agriculture can be reduced and made more sustainable.

3. Monitoring crop health

IoT sensors can help farmers **monitor the health of their crops and detect problems such as pests and diseases before they spread**. This allows them to take preventative measures to avoid crop loss. Continuous monitoring of crop health can also help farmers **identify patterns and trends over time**, which can be useful for **improving cultivation practices and optimising yields.** In addition, early detection of crop problems can help farmers reduce costs associated with treatments and crop loss.

A real-world example of IoT application in the world of agriculture is a case from Kenya, where **farmers at Twiga Foods' Takuwa farm [REF-11]** managed to **reduce pesticide consumption thanks to IoT**. They have a **smart weather station** that provides **real-time data**. They use this data to implement **more effective farming methods**, both in terms of irrigation and pesticide application. This has enabled **them to make data-driven decisions** and **adjust their farming practices** accurately and **efficiently.**

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4. Automation of agricultural tasks:

IoT technology can help automate many agricultural tasks, which **can save time and labour, reduce errors and increase efficiency.** With the help of sensors and connected devices, farmers can **control and monitor farming tasks** in real time.For example, in irrigation, farmers can use **soil moisture sensors** to determine **when irrigation is needed and how much water is required**. In **harvesting**, farmers can use robots or autonomous machinery to **harvest crops efficiently and accurately**, without the need for human labour. In addition, the **data collected** from these **automated tasks** can be analysed and used to further optimise farming practices.

Automating agricultural tasks can help farmers **improve productivity**, and streamline their processes, which may be especially important in a context of rising global food demand and labour shortages in some regions.

5. Resource optimisation:

IoT can help farmers **optimise the use of resources**, such as water and fertiliser. By monitoring soil and weather conditions, farmers can adjust the amount of water and fertiliser they use to **maximise production and minimise waste.** With the help of sensors and connected devices, farmers can monitor soil and weather conditions in **real time.**

For example, soil moisture sensors can help farmers determine the **amount of water needed to maintain proper soil moisture levels**. This allows farmers to apply only the necessary amount of water, avoiding waste and reducing the cost of irrigation.

The sensors can also measure the concentration of nutrients in the soil and the amount of fertiliser needed to maximise yields. By adjusting the amount of fertiliser applied according to crop needs, farmers can **minimise nutrient loss in the soil and reduce costs.**

Resource optimisation can not only help farmers reduce costs and increase efficiency but can also have a **positive impact on the environment** by reducing the overuse of water and fertilisers, which can be harmful to natural ecosystems.

6. **Tracking the supply chain:**

IoT can help farmers follow the **path of their products** from the field to their consumers' tables. This allows them to **trace the origin of food and ensure food safety.**

With the help of connected devices and tracking technologies, farmers can monitor the quality of produce and ensure that it meets food safety standards. In addition, they **can trace the origin of products** and provide detailed information on the production process, which can **increase consumer confidence** in agricultural products.

In addition, **supply chain tracking** can help **farmers identify potential problems or risks in production,** which can improve efficiency and reduce supply chain costs. For example, farmers can use temperature and humidity sensors to monitor the transport of produce to ensure that it remains in optimal condition throughout the distribution process.

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Tracking the supply chain with the help of IoT **can improve food safety, increase transparency and consumer confidence, and improve efficiency and reduce costs in the agricultural supply chain.**

In conclusion, IoT **has the potential to transform the way agriculture is produced and managed.** By enabling real-time monitoring of weather and soil conditions, monitoring crop health, automating agricultural tasks, optimising resources and tracking the supply chain, IoT can improve efficiency in agricultural production and increase food security.

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5. Tools

When implementing a complete IoT solution, **different types of components** need to be considered **[REF-12]** such as **sensors and actuators,** connectivity, IoT cloud, analysis and management of the data extracted from the IoT, and finally, the devices and interface.

In this sense, some of these components, tools and applications available on the market that can help the farmer to monitor and manage his crops are listed below. **Several examples** are presented below:

- **Agroptima (REF 13)** : It is an agricultural management tool that allows **planning and monitoring of crops, scheduling tasks and monitoring of phytosanitary treatments.** It also provides meteorological information and recommendations on the right time for agricultural work. In addition, it is synchronised with SIGPAC. The price varies according to the area to be managed and the users, and there are three different plans with different functionalities.

- **CropX (REF 14)** : This is a precision farming solution that **uses IoT sensors to measure soil moisture, temperature and electrical conductivity**. It provides a cloud-based platform that analyses the data and gives recommendations on how much water and fertiliser to apply to crops. It also helps reduce the overuse of water and fertiliser.

- Libelium (REF 15) : Libelium offers a **wide variety of sensors and IoT devices to monitor different environmental variables** in agricultural, urban and environmental applications. In addition, it offers various connectivity options, including WiFi, Bluetooth and 4G.

- Pycno (REF 16) : It is a platform that provides real-time **information on irrigation and crop climate through sensors that measure soil moisture**, temperature and air humidity, among others. This tool enables water and energy savings by avoiding unnecessary irrigation and offers a user-friendly interface for data analysis.

However, in many cases**, an internet connection is needed to transmit data from IoT tools used in agriculture**. This should not be a clear impediment to implementing such solutions, as there are alternatives. On the one hand, there are **IoT solutions that do not require an internet connection** or that allow local storage of data. These solutions are **known as IoT edge computing**. [REF-17]

For rural environments **without internet connectivity** and electricity, there are also solutions that work with low-power, low-bandwidth communication technologies, such as **low-power wide area networks (LPWANs) [REF-18]** and **satellite communication technology. Low-power wide area networks, such as LoRaWAN and Sigfox, [REF-19]** are ideal for **rural environments** due to **their low power consumption** and ability to transmit data over long distances. These technologies can be used to connect IoT devices to a network, even in **remote rural areas.**

Satellite communication technology is another option for rural environments without internet connectivity. IoT devices can **transmit data over a satellite connection so that farmers can monitor and control their crops and animals from anywhere**. In addition, for **rural environments without electricity,** solutions that run on **rechargeable batteries or solar panels can be used to power IoT devices.**

6. Conclusions

In conclusion, the use of **IoT technology** in agriculture has **great potential to improve the efficiency, profitability and sustainability of the sector.** With the ability to **collect real-time data and provide valuable information to farmers, IoT systems can help optimise resource use, improve production, reduce costs and increase crop quality.**

In addition to the benefits of IoT technology in agriculture, it is important for **SMEs and self-employed farmers to be aware of the technology needs that these tools require**. **Most IoT applications in agriculture** require a **good internet connection and, in some cases, a stable power supply** to keep sensors and devices connected and running. It is essential that **farmers and producers are aware of these requirements and can adapt their systems to ensure proper use of the technology.**

On the other hand**, data security and privacy are important challenges that need to be addressed**. The **data generated** by IoT devices in agriculture is **valuable and needs to be protected to avoid potential cyber attacks and to ensure the confidentiality of business information**. It is therefore **important that IoT tools used in agriculture are designed with high security and privacy standards**, and that farmers and producers are trained to handle this data securely..

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In conclusion, IoT technology can **be a powerful tool for improving efficiency and productivity in agriculture, helping SMEs and the self-employed to make informed decisions based on real-time data**. While there are **challenges to be addressed**, with the right **education and training** and the use of IoT tools designed with high security and privacy standards, **farmers and producers can effectively adopt this technology and improve their operations and business outcomes.**

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