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Internet of Things technologies in precision dairy farming

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1 Introduction

This book is dedicated to precision dairy farming. The terms precision dairy farming, precision agriculture, precision livestock farming and smart farming overlap in meaning. A few semantic differences occur as discussed in Lokhorst (2018). Precision agriculture and precision livestock farming (PLF) are core to satisfying the ever-increasing worldwide demand for safe, good-quality food products, whilst allaying societal concerns over animal welfare and substantially reducing impacts on environmental resources. The principle is that if the needs of animals and crops are satisfied at the highest granularity (i.e. at the level of the individual animal), the farmers and the supply chain – including consumers – will benefit.

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Over the recent past, the sector has been subject to an increasing drive towards efficiency and performance enhancement to improve sustainability. A direct consequence is that the farmers have more animals per farm and consequently have less time to carry out traditional manual practices. Therefore, farmers are becoming increasingly reliant on technology. Thus, there is a growing range of opportunities for the delivery of precision farming solutions through the integration of a mix of hardware and software technologies. In turn, the evolution to new business models based on provisioning a range of services to the agricultural community becomes possible, further fuelling the ready uptake of technology for the benefit of all operating within the supply chain. Several definitions and descriptions are used for the same concept.

The solutions required to support this evolution harness a number of technologies that follow Internet of Things (IoT) principles (Hassan et al., 2015; Atzori et al., 2017). Internet of Things is a platform that allows a network of devices to communicate, gather data and process information collaboratively in the service of individuals or processes. An IoT system can be characterised by the following components (inspired by Figure 1 and described in Lokhorst (2022)):

- **Sensor(s)**: a device that measures a specific feature of an object or environment. Sensors are responsible for the conversion of measured phenomena into a quantity, which can be stored in a data acquisition system, possibly in the cloud. The output of a sensor can be an analogue signal, e.g. an electric signal (in current, voltage or frequency) which, in

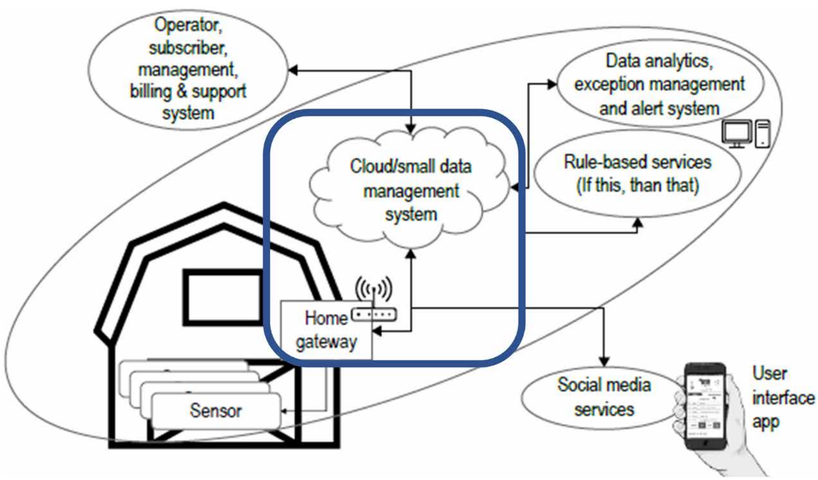

Figure 1 Basic aspects that should be part of an IoT system (according to Cees Link from Green Peak).

the data acquisition system, is translated into a digital number, or a direct digital signal, a binary code or series of digital values. In general, the following phenomena can be detected by sensors: biological, chemical, electric, electromagnetic, heat/temperature, magnetic, mechanical motion (displacement, velocity, acceleration, etc.), optical and radioactive phenomena.

- **(Home) gateway**: the system that is responsible for connecting physical sensors to the Internet or to each other in an in-house communication network. This component is not always needed in IoT developments as sometimes sensors are connected directly to the Internet through peer-to-peer communication without the need for a gateway.
- **Cloud/small data management system**: a system that stores and handles data and information from the sensor systems and the connection through the (home) gateway in the Internet data storage system(s). These data storage systems can be either in the cloud or distributed to diverse locations.
- **Data analytics, exception management, rule-based system and alert system**: an intelligent system in an IoT system that transforms data into information, incorporating knowledge and action. A variety of intelligence solutions are available from data analytics, modelling and artificial intelligence.
- **Operator, subscriber, management billing and support system**: the organisation that is required for an IoT to function. For an IoT system, it should be clear who the operator and the subscribers (or clients) are and how their relation in the form of billing mechanisms and support are organised. This can be seen as the underlying business model for the IoT system based on transactions. From the viewpoint of the General Data Protection Regulation, it must be clear who is the Data controller and who is the Data processor.
- **User interface apps (social media services)**: the direct interface users interact with when using IoT technology. Transformed data, such as alerts or actions, need to be effectively communicated to users. Since the backbone of an IoT system is strong integration with the Internet, a specifically designed user interface app or general use of social media and/or other platforms are part of the IoT system. This communication interface can be achieved through specifically designed user interface apps or by general-purpose social media platforms.

Since 2010 the EU has promoted IoT research and innovation programmes for several sectors. Large-scale pilots have supported the deployment of IoT solutions in Europe. This has been achieved through integration of advanced IoT technologies across the value chain, demonstration of multiple IoT applications at scale and across a range of user applications, and application of IoT technology in ways as close as possible to operational conditions. Large-scale pilots were targeted, goal-driven initiatives that proposed IoT approaches to specific, real-life industrial/societal challenges. Pilots are autonomous entities that involve stakeholders from both the supply and the demand side, and contain all the technological and innovation elements – the tasks related to the use, application and deployment as well as development, testing and integration activities.

2 Internet of Things technologies for agriculture

For agriculture and food production in Europe, the large-scale pilot Internet of Food and Farming (www.IoF2020.eu) was started in 2017. Agri-food is a particularly challenging domain for IoT because the 'things' involved are often living, moving or natural objects, such as plants, animals, soil and perishable food products. This means that IoT devices (e.g. microprocessors, sensors, antennas) cannot be easily embedded in the products themselves. Furthermore, they must operate in harsh environments and remote areas (open fields, stables, etc.) requiring them to be energy-autonomous and capable of handling Internet connectivity in rural areas. They also operate in highly complex, dynamic environments (such as open fields in constantly changing environmental conditions) which make data acquisition and analysis hugely challenging.

The IoF2020 Project envisioned development towards self-adaptive systems where smart objects operate, make decisions and learn autonomously. The heart of the project structure was formed by different use cases in diverse sectors of the agriculture and food sector, including both conventional and organic farming. The use cases of the dairy trial were reported in Lokhorst (2022).

The IoF2020 project developed the initial concept of IoT applications in the livestock sector introduced by Gray et al. (2017). Since then new developments have taken place in IoT technologies. In this chapter, we aim to highlight key issues related to IoT from a historical perspective, as understanding its evolution over time provides valuable insights into the importance of IoT elements and their relevance. Since this part of the book focuses on data sharing, we focus on the (home)gateway and cloud/small data management system aspects of IoT. They connect the sensors, data analytics, operators and the social media devices and are responsible for data storage and data transport.

The following key issues will be discussed in historical perspective (Figure 2):

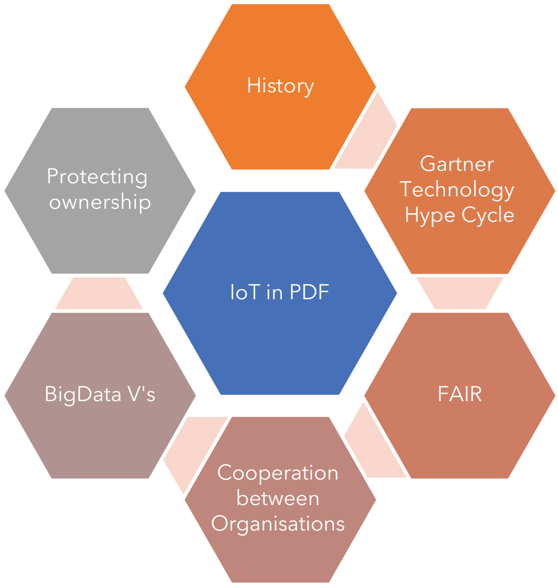

Figure 2 Key aspects related to IoT in PDF.

- The FAIR principle of data sharing. FAIR is the acronym for Findable, Accessible, Interoperable and Reusable. See Kutha Krisnawijaya et al. (2025) for implementation experiences. The FAIR data principle states that it should be possible to find data, there should be information about how to gain Access to them, they should be compatible with other data or be Interoperable and Reusable.
- The technology and organisational developments in data collection, storage and management. Technological developments are, in general, sense predicted and explained by using the Gartner's hype cycle (Dedehayir and Steinert, 2016). On an organisational level, the role of individual organisations and how they cooperate in various (production) networks has undergone drastic change.
- Data, information and knowledge are the glue for cooperation. These are part of the Big Data concept, also introduced by Lokhorst et al. (2019). BigData (De Mauro et al., 2016) is a collection of data from many different sources and is often described by five characteristic V's: volume, value, variety, velocity and veracity.
- The importance of security, safety and ownership of data has also become a key issue. The awareness of the value of data and the efforts needed to manage the legal and social aspects of data are growing rapidly (van den Burg et al., 2021).

3 Key developments in the 1980s and 1990s: the Dutch Informatics National Simulation Program

The historic perspective in this chapter will be mainly from the authors' perspectives and can be used as an example and point of comparison for other countries and contexts. Due to developments in the EU, the Dutch perspective is intertwined with the European perspective. This chapter evaluates the following four periods:

- The Dutch national Informatics National Stimulation Program initiative in the 1980s and 1990s;
- Stand-alone (sensor) application developments in the 1990s;
- Cloud solutions and new IoT technologies in the 2000s and 2010s; and
- Data platforms and data spaces in the 2020s.

This section discusses the first of these periods.

First developed in the 1970s, personal computers (PCs) started to become established and widely known in the 1980s. Information and communication technologies (ICT) moved from a primarily research environment and became available for business application development. At this time, the Dutch government took the initiative to launch a national program: INSP. This program was developed to stimulate the adoption of ICT technologies (Landbouw-Economisch Instituut and Landelijke Vereniging van Accountants- en Belastingadviesbureaux, 1985). As a starting point, the Project constructed process and data models for all relevant sectors. The program urged developers to develop uniform and clear definitions of individual variables to promote standardisation. On an organisational level, the program helped establish the Agricultural Telematica Center (ATC). After the termination of the product boards and the Landbouwschap (the Agricultural Board), the ATC split and created sector-specific branch organisations. For the dairy sector, this branch organisation was called TAURUS and soon started to attract industry partners.

Research institutes were involved in the information models and building of the first prototypes of Farm Management Information Systems (FMIS). New companies like Uniform Agri and Agrovision popped up and started selling their first commercial versions of FMIS. There was no discussion on FAIR data sharing, since everything was concentrated on the farm. These FMIS used relational databases and PC technology as key technological drivers. Backups needed to be made on the farm itself. The appearance of automatic milking systems (AMS) occurred during this period, driving digitalisation of more traditional milking systems. The milking barn became a key point for collecting dairy production data. This development was stimulated by new free stall housing systems. Advances in electronic identification also made it possible to automate the delivery of concentrate feed to animals. This led to an early recognition of the value of connecting these process computers to the FMIS. For this, the Electronic Data Interchange (EDI) protocol was developed and supported by TAURUS. Harmonisation of data elements in the Agricultural Data Elements Database (ADED) also started and is still used.

Companies used these developments as a first attempt to work on the interoperability of systems, but it appeared that a lot of custom-made solutions were needed. Part of the explanation is that the big milking companies (with the exception of Lely) were not located in the Netherlands, so were not part of the national drive for standardisation. In this period, work to promote global data standardisation by the International Organisation for Standardization (ISO) and the Global Standard for Livestock Data (ICAR) started, focused on standardisation and interoperability of electronic identification and milk meter data.

This period can be seen as the starting period for data-driven dairy management, and new types of organisations were formed for standardisation and data exchange. However, these initiatives were all initially directed at the individual dairy farm. BigData and ownership of data were not relevant in this period. Data was stored on PCs with backups on floppy disks and data tapes. They were stored on the farm itself. The milking system data were also locally stored.

4 Key developments in the 1990s: stand-alone sensor technologies

Due to technological developments in the 1990s in wireless sensor networks and Internet connection, the 1990s saw the breakthrough and development of stand-alone sensors. A good example is the activity sensor for oestrus detection. Although development had already started earlier with the first patents in the 1970s, it became possible to both acquire data remotely and at two-hourly intervals instead of twice a day. This fitted much better with the requirements for accurate and timely oestrus detection. In this period, new types of bolus and other sensor appeared. An example is the company Cow Manager which switched in this period from being a FMIS company to selling ear tags to measure ear temperature and activity (Weber et al., 2022). Another technological development was in using object-oriented programming, which opened up new opportunities for efficient software coding. In this period, there was a much greater focus on the findability and accessibility of data.

Companies began to explore the benefits of bringing sensor and FMIS data together so they could add value by providing standardised overviews and benchmarks to show the relative position of individual farms compared to others. In this period, connecting data in the dairy chain developed.

New stakeholders became involved, and larger dairy companies used their cooperative background and power to bring data together in quality systems which then applied to all their farmer members or customers.

On an organisational level, the branch organisations of different agricultural sectors were brought together to create the AgroConnect Organisation. AgroConnect still exists (as of 2025) to promote eBusiness in agriculture. Members of AgroConnect include agricultural cooperatives, the food processing industry, solution providers, advisory services, accountants, data sharing platforms and governmental organisations. A special group are the FMIS providers. AgroConnect has further developed to establish and maintain standard data models, interfaces and protocol definitions for data exchange. Given the global nature of agri-food supply chains, it has also started to cooperate with ISO, United Nations Centre for Trade Facilitation and Electronic Business (UN/CEFACT), and Global Standards 1 (GS1).

This period started the Big Data orientation, as FMIS and application management system (AMS) companies started to collect, store and use data from all their clients in a company-based central web-based database. The volume of data started to increase, but the variety of data remained rather limited. In the 1990s there were still no discussions on ownership and value of data.

5 Key developments in the 2000s and 2010s: cloud solutions and the development of IoT technologies

Although the ability to work in the cloud started in the 1990s, it became a key driver in the 2000s and 2010s. Remote connection, data handling, software development and software maintenance became possible. This was, and still is, a big challenge for companies active in this field. FMIS and AMS systems were reprogrammed, and the way data were treated and stored changed drastically. The Internet became a success and part of normal life, and it stimulated the trend for IoT solutions. IoT opened opportunities for new start-ups and small and medium-sized enterprises (SMEs) to develop specific products for farmers. There was less urgency to integrate their systems in the FMIS and AMS environment. Connectivity was driving these applications. From an EU perspective, this was also the period of the IoF2020 Project focused on IoT technologies. In the dairy industry, there were now a few selected use cases that could be analysed and compared, as discussed in Lokhorst (2022). At an organisational level, AgroConnect worked further on standards for data exchange, and the variety of organisations involved in data exchange in the dairy sector increased substantially.

In this period, the first data platforms and data warehouses developed. In the Netherlands, a Smart Dairy Farming Project was created. The consortium consisted of research organisations, dairy farmers, SMEs for smart data solutions and companies involved in breeding, feed and dairy product processing. All embarked on an intensive journey to explore and capitalise on the added value of real-time cow-oriented data collection and analysis and its potential to further improve the lifetime productivity of dairy cows.

The ‘Ijkdijk’ model for data exchange developed by the Netherlands Organisation for Applied Scientific Research (TNO) for another sector was also introduced. This was to form the basis for the later creation of JoinData as an organisation in the Netherlands (as discussed later). In the JoinData concept, the data ownership issue was identified and addressed in a way that recognised farmers as data owners who could then give permission to other organisations to use their data. It also gave a boost to interoperability since producers became aware that they had to make their own application programming interfaces (APIs) or other solutions to transfer or obtain specific data. Earlier initiatives to develop standardised definitions of data objects and processes began to demonstrate their value. New data platforms were created. An example is the establishment of the Data Dairy Warehouse to collect data from individual cows and farms. The value of dairy data and these warehouses became so strategic that the big AMS companies began to acquire FMIS and warehouse companies.

These developments coincided with the further development in the Big Data field. It became possible to handle not only higher data volumes but also more data variety and value started to increase. Possibilities to analyse data also increased in this period with the first new AI-based applications popping up. A good example is the start-up company Connecterra that uses real-time sensor data to create actionable insights for dairy farmers.

6 Key developments in the 2020s: the development of data platforms and data spaces

The 2020s saw significant advances in data handling and storage, driving the development of new data platforms and data spaces. Different data platforms like JoinData and DjustConnect became fully operational commercially in the dairy sector. Continuing developments in digital strategy in the EU have resulted in new projects and ideas, e.g. in FAIR data and dataspaces. Projects like Smart Agri Hubs, agROBOfood, agrifoodTEF, AgriDataSpace and GAIA-x are underway, mainly driven by universities, research institutes and the telecom industry. They seek to connect dataspaces to a variety of private and public market players. The dairy sector is looking at these data handling issues and has been involved with some of these developments. These developments are coming mainly from other sectors and in the international arena.

The challenge for the dairy sector is to see which of these broader developments will be beneficial. These developments require further international standardisation which can be seen in the development of ontologies and new ICAR activities for standardisation of sensor-derived data. As this suggests, beyond the data, there is a need to develop and standardise metadata describing data. International data platforms and data spaces will drive reusability and variety of data. New applications based on vision, sound and social media will increase the variety of data to cover, and AI has the promise to add significant new value to data. The role of the farmer in these developments has become almost invisible, which raises new questions about trust, business models and farmer ownership of data. It is clear that the dairy data market has become a playground of many new international players. However, to protect farmers' data ownership, initiatives like JoinData and DjustConnect have built upon the EU Code of Conduct on Agricultural Data Sharing, with contractual agreements which enable farmers to retain full control over their data while also promoting interoperability and reusability (Ryan et al., 2024).

AgroConnect is still relevant to these developments but the focus is more on international standardisation and security and safety of data. An example is the development of the 'Agrifood Cyber Resilience Self-Assessment Tool'. As developers of this tool state: 'in the agricultural sector a revolution is under way with robots, drones, digitization and internationalization of the market'. The application of IT in agriculture and the food chain is increasing at a phenomenal rate. More and more companies in the agri-food supply chain use smart farming technologies. There is a growing need for supply chain transparency. Huge volumes of data are now used in (near) real time for a growing range of purposes. All this requires a lot from the companies that are active in this market, because of the speed and frequency with which data must be made available. Members of AgroConnect share the vision for an open information architecture that is necessary for the successful development of Dutch agribusiness. It is essential to have a commonly agreed framework on how to exchange data. AgroConnect thus facilitates activities where standardisation, collaboration and knowledge sharing can take shape.

7 Assessing technology developments: the growing importance of data

The historic perspective described in the previous sections provides only a summarised overview of the main developments from a mainly Dutch perspective. It shows how the awareness of the role of data and data exchange has been transformed. Data have become the binding factor between organisations in production chains/networks with huge strategic value. Technological developments in different fields have substantially changed the role of dairy farmers. The shift from being the centre point to a more 'anonymous' data provider has affected trust and willingness to cooperate in providing data.

It is therefore particularly important that new concepts governing control of and permission to use data have been introduced by the JoinData initiative, reflecting a wider interest in the safety and security of data and data exchange. There are now new EU and national rules which protect the rights of data providers such as farmers. Farm Data Spaces and AI will have effects on the data dairy market, but it is not clear what this means for the position of different stakeholders.

More and more stakeholders will be involved. In the Netherlands, a new development has started where non-governmental organisations (NGOs) and policy makers are developing new policies to monitor and reduce greenhouse gas (GHG) emissions using sensor technologies. Farmers can then use sensor-based information to monitor and show e.g. that their GHG and ammonia emission are not passing a predetermined goal that is part of a permit given by a competent authority. This will increase the need for secure, safe and trusted data from dairy farms.

8 Case study: JoinData and DjustConnect

More background relating to this case study can be found at the JoinData initiative (https://join-data.nl/en/about-joindata/) in the Netherlands and in its application as DjustConnect in Flanders (Belgium) (https://djustconnect.be/en). The idea for JoinData arose during the Smart Dairy Farming (SDF) Initiative. This initiative arose from collaboration between companies, research institutions, TNO and dairy farmers. Wageningen Livestock Research (part of Wageningen University & Research) and the Northern Development Company were key drivers to stimulate data awareness, precision dairy farming among farmers and others in developing smart applications to increase the lifespan of dairy cows in the northern part of the Netherlands (Figure 3).

Since they could see the potential of the data exchange model developed by TNO, a strategic choice was to ask the big dairy cooperatives – CRV, FrieslandCampina and Agrifirm – to take ownership of the project. They became involved initially through the SDF Project. In 2017 they were key to setting up JoinData as a non-profit cooperative. Other partners soon joined, including farmers through the Agricultural and Horticultural Organization (LTO), EDI-CIRCLE (a partnership of accountants in Data Exchange) and Rabobank. In 2019 and 2020 the focus was on data exchange in the dairy sector. Subsequently the arable farming cooperatives Cosun and Avebe joined, as well as the companies Vion and POV (Producers Organisation for Pig Farming) from the pig sector. JoinData has thus become an intersectoral company that specialises in trusted data exchange, particularly in protecting farmer data and securing permission for its use by others. Subsequently the membership of FrieslandCampina has been transferred to the Dutch Dairy Organisation (NZO).

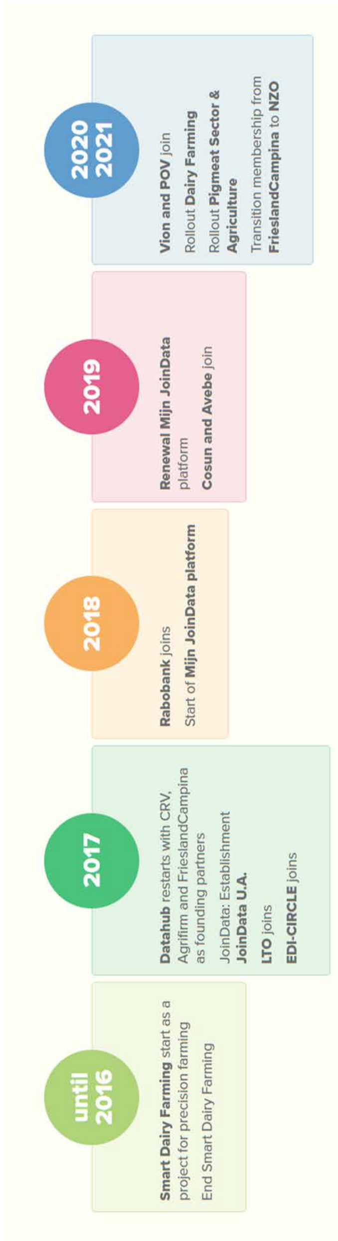

Figure 3 Timeline for development of JoinData. Aspects related to IoT in PDF.

JoinData has a so-called ‘digital data highway’. It ensures efficient and safe ‘transport’ of data. The most important part of the JoinData platform (the unique selling point) is that it offers an authorisation mechanism/register for the farmer to manage authorisations (consent) to third parties to make use of the farmer’s data for a specific purpose. This gives farmers full control of the farm’s data. Sharing data via JoinData minimises the risk that data are subjected to unauthorised use or that a data leak leads to negative publicity. JoinData guarantees that data traffic is safe. JoinData is ISO 27001 certified. This means that annual audits take place regarding data processing and security. JoinData always makes sure that their methods and procedures comply with current laws and regulations, such as the General Data Protection Regulation (GDPR).

While Dutch researchers are not directly involved in the JoinData organisation, its success inspired ILVO, the Flanders research institute active in several European digitalisation initiatives, to create the DjustConnect platform (https://djustconnect.be/en/who-are-we). DjustConnect originated as an EFRO (European Fund for Regional Development) Project called *Datahub for AgroFood*. Supported by its founding companies (AVEVE, Boerenbond, CRV, DGZ, and Milcobel), it has since evolved into a fully mature platform that successfully connects data providers and users, enabling data-driven applications to thrive.

As a non-commercial and neutral party in the ecosystem, ILVO hosts DjustConnect as a trusted data exchange platform. The mission of DjustConnect is to stimulate data exchange in the agri-food sector taking into account different stakeholders, improve data standardisation and quality, eliminate repetitive, boring data entries, unlock the full potential of applications and create value throughout the supply chain. At the moment, DjustConnect has 3000 farmers to its platform, offering a value proposition that includes reducing administrative burdens, professionalising business management and improving decision-making. Figure 4 shows the monthly growth of DjustConnect with a peak in 2024 due to a specific promotional campaign.

DjustConnect is built on a foundation of respect and trust. While data is often compared to oil due to its potential to unlock countless applications, provide insights and drive optimisation, this analogy oversimplifies its true nature. Unlike oil, data is not a scarce or finite resource. Instead, it is a renewable, reusable and context-dependent asset that increases in value through collaboration, innovation and ethical use.

Realising the full potential of data requires access to diverse data sources, each contributed by originators who play a critical role in the ecosystem. DjustConnect ensures that these data originators retain control over their contributions by implementing a system based on trust and permissions. The platform guarantees that data are exchanged only with explicit consent and that sharing stops immediately if permissions are revoked. This trust-centric

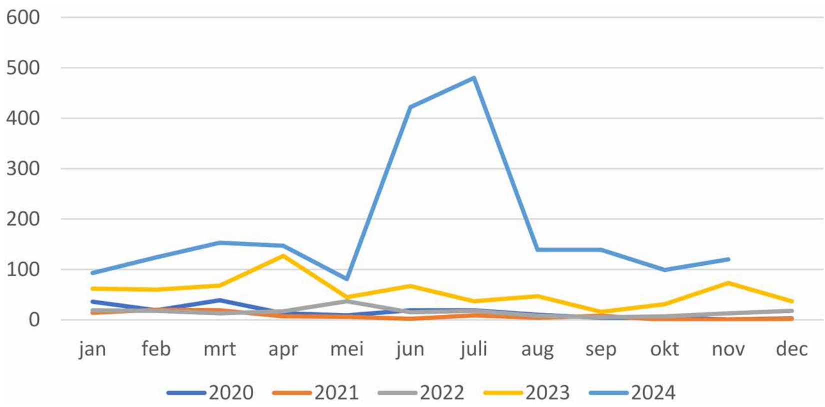

Figure 4 Monthly figures of new farmers joining DjustConnect.

approach is supported by a clear legal contract for all ecosystem participants to accept, ensuring compliance and accountability. By fostering trust, respecting data ownership and enabling secure sharing, DjustConnect supports the development of innovative, data-driven applications while addressing the rights of all stakeholders.

JoinData and DjustConnect are based on the same principles, and they have filled in a gap in data exchange. Involvement of a variety of organisations is a prerequisite, but it was very important to create a third, trusted party with involvement by farmers. It will be interesting to see how these two 'Dutch language oriented' initiatives can become inspiration for more European countries in the coming years.

9 Future trends in research

It is important that new developments are fully explored (e.g. by the research community) and that together with a variety of stakeholders, experiments will be set up to explore the value and applicability of these developments. There is a growing need for standardising calculation rules for a variety of key performance indicators (KPIs) relating to sustainability, welfare and emissions. Researchers can play an important role in setting standard calculation rules, developing and maintaining calculation modules as independent and objective cloud applications that can be accessed through standard APIs. However, it looks like the developments go much faster and are also more diverse. Ethical, legal, societal and organisational issues also need to be studied. Whereas in the past, most research was paid for by governments and farmers, companies are now key drivers. Companies work on new innovative processes and products to support their partners in production networks in the dairy sector. Multinationals, SMEs and start-ups are all involved in this. In addition, companies with limited agricultural knowledge are also becoming interested in the dairy market.

Given its particular focus on digital strategy, the EU can become a leading and trusted region for the creation and application of knowledge. It has worked consistently on building the infrastructure for safe, secure and trusted data exchange to support the agricultural sector to produce sustainable and affordable food. Digital strategy in the EU focuses on stimulation and support for the development of AI-, Robotic- and BigData-related products and services. This is reflected in the Green Deal and the Farm to Fork Initiatives. A key element of this digital transformation is the Common European Agricultural Data Space (CEADS), a European initiative to enable secure, interoperable and trusted agricultural data exchange. CEADS aims to empower farmers and stakeholders by ensuring data sovereignty while fostering innovation and improving decision-making throughout the agricultural value chain. Strategy can also be seen in developments in the European Food Safety Authority (EFSA) where data and digitalisation based on real-time sensor information has become relevant for a variety of safety monitoring programmes. All these developments create new challenges for researchers to address the needs of the dairy farming industries in their home countries.

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