Dairy farming in the era of artificial intelligence: trend or a real game changer?

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Dairy Farming in the Era of Artificial Intelligence: Trend or a real game changer?

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Abstract

Artificial Intelligence (AI) is reshaping the world as we know it, impacting all aspects of modern society, basically due to the advances in computer power, data availability, and AI algorithms. The dairy sector is also on the move, from the exponential growth in AI research, to ready to use AI-based products, this new evolution to Dairy 4.0 represents a potential "game-changer" for the dairy sector, to afront challenges regarding sustainability, welfare, and profitability. To explore this possibility this research reflection, discusses the main drivers in the field of AI, from the origins, challenges, and opportunities. Further, we present a multidimensional vision considering factors that are not commonly considered in dairy research, such as geopolitical aspects and legal regulations that can have an impact on the application of AI in the dairy sector. This is just the beginning of the third tide of AI, and a future is still ahead. For now, the current advances in AI at on-farm level seem limited and based on the revised data, we believe that AI can be a "game-changer" only if AI is integrated with other components of Dairy 4.0 such as robotics and is fully adopted by dairy farmers.

Keywords: Dairy 4.0; innovation; artificial intelligence; machine learning; deep learning; computer vision.

Throughout its history, humanity has experienced several industrial revolutions that have transformed the way we live, and dairy farms have adapted and taken advantage of these technological advances, incorporating them into their production processes. Today, with the arrival of the Fourth Industrial Revolution (4IR), the dairy sector is adapting these technologies to the new concept of Dairy 4.0 under development, and one of the most promising of those technologies is AI (Hassoun et al., 2023). Since the 1950s, AI has gone through several periods of low and high development, but in recent years it has gained unprecedented strength. At the macro level of innovation systems, the big tech companies such as Open AI, Meta AI, or Google AI, have been leading the AI research at a basic level due to their infrastructure. But not only the big tech is in it, but also several country governments consider AI as a key technology.

The first scientific reports implementing AI related to dairy science appeared in the mid-1990s (i.e., Nielen et al., 1995) and have grown exponentially since the mid-2010s. Although there are great advances in the AI sector, the use of this technology in the dairy sector will depend on the feasibility to be applied on-farm; particularly facing the challenges around data integration and farmers' technical capabilities. Regarding data integration, the continuous big-data collection from different sensors as described by Knight (2020), is divided by: at cow (i.e., data from accelerometers, temperature, heart rate and pH analysis), near cow (i.e., video and sound recordings, climate data, feed analysis and GPS) and from cow (i.e., milk, blood, hair, DNA, and faeces), which are usually stored in the cloud, and with continuous development of AI technologies.

The dairy sector faces important sustainability challenges in the coming decades, but the question of what impact AI could have on these challenges remains unclear. Due to the current trends in AI in all aspects of society, the present research reflection aims to discuss if AI could be considered a “game-changer” for the dairy sector. To explore this possibility, we used a multidimensional view starting by discussing the origins of AI to the current available on-farm applications, including current challenges and opportunities. A “game-changer” in global terms, are those events and developments that shape the course of history (Avelino et al., 2017). Now, several studies have been published in other areas such as health, economics, and education, but for dairy science, this concept has not been coined and thus, AI has not been cataloged as a “game-changer”. Although this research reflection focuses on

AI, other pillars of Dairy 4.0 will also be considered due to their importance and their vital coexistence with AI.

The fourth industrial revolution and Dairy 4.0

Since the early 21st century, the world has been immersed in the fourth industrial revolution (4IR), a term developed by Klaus Schwab, during the World Economic Forum Annual Meeting 2016. But the term Industry 4.0, originated from a German project designed to stimulate the high-tech industry between 2011 and 2015 (Philbeck and Davis, 2019). Several adaptations to these terms have been proposed to identify agri-food areas, such as Agriculture 4.0, Precision Agriculture, Dairy 4.0, Smart-Farming, Smart Dairies, and Precision Livestock Farming. Hassoun et al. (2023) suggested that the main pillars of Dairy 4.0 are: AI, big data, robotics, 3D printing, internet of things (IoT), and blockchain (enabling the provision of real-time data of milk from farm to fork approach ensuring transparency and food security; Gehlot et al., 2022). However, other 4IR technologies are also important including simulation, quantum computing, augmented reality, cloud computing, and horizontal and vertical integration.

Today's leading Dairy 4.0 technologies, which have been in the market for several years, in dairy systems are automated milking systems (robotic milking systems without the direct assistance of milking staff), animal monitoring systems (such as neck collars for heat detection, health and behavioral monitoring sensors, eating patterns monitoring devices, calving alerts, etc.), automatic feed dispensers, robotic feed pushers and cleaners, milk quality and mastitis detection systems, turn-key system designed to measure greenhouse gas emissions (i.e., CH_4 and CO_2), and other based largely on sensors (Knight, 2019; Krpalkova et al., 2021). The main benefits of implementing the 4IR are increased efficiency and productivity, revenue gain, and minimizing human/manual errors (Neethirajan, 2020; Jerhamre et al., 2022).

Artificial Intelligence: origins and framework

The origins of modern AI can be traced back to the 1950s when pioneers in computer science were exploring whether computers could be able to think. So, AI can be defined as a simulation of human intelligence (replicated by a system or a machine to perceive their environment, learn, and make decisions), but until now a conclusive definition has not been established and several proposals remain under debate (Wang, 2019; Hassoun et al., 2023). In recent years, there has been a rapid growth in technological advancements such as computer power, with large availability of data (“big data”) allowing AI to evolve from mere theory to real-world applications on an unprecedented scale (Topol, 2019).

The framework of AI is organized into different layers according to Xu et al. (2021):

- Infrastructure layer (data, machine and deep learning algorithms, storage, and computing power).
- Perception layer (computer vision, speech recognition, and synthesis) that allows machines to see and hear.
- Cognitive layer (natural language processing) provides superior capabilities of induction and reasoning.
- Decision-making layer (expert systems and automatic planning) allows AI to make complex decisions such interpretation, diagnosis, and prediction.

Periods of AI technological development

Over time, the field of AI has passed through several periods of ups and downs in knowledge development, commonly known as seasons, divided into tides of summers (ups) and winters (downs) (Toosi et al., 2021). The first winter occurred from 1973 to 1980 and the second from 1987 to 1993 (Haenlein and Kaplan, 2019). The main reasons for the first winter were the disappointments in machine translation and the consequent Lighthill report for the British Science Research Council with the conclusion that the expectations of AI development projects were exaggerated. Consequently, the UK cut the funding to AI, and other agencies like DARPA (Defense Advanced Research Projects Agency) redirected the funding to more applied AI projects. Although the possibility of the sector of AI going through another winter is possible, at the same time the chances are probably slimmer than before because of the large financial investment of big tech companies in the sector, as well as the government support which sees the potential of AI to provide financial growth in many industries and enhance military capabilities. At the end of the second winter, the first publications on dairy dealing with AI started to appear and grow exponentially (Nielen et al., 1995; Hassoun et al., 2023). As shown in Figure 1, this is explained by the achievements of the third summer of AI, and this trend is not expected to stop.

The fundamentals of machine learning, deep learning, and computer vision

Machine learning (ML) systems are classified according to the amount and type of supervision during training. Four major categories exist, supervised learning, unsupervised learning, semisupervised learning, and reinforcement learning. The most used algorithms in supervised learning are k-nearest neighbors (KNN), support vector machines (SVM), decision trees (DT), and random forest (RF). For example, the module for Python Scikit-learn contains a vast variety of ML algorithms. Another example is Weka, which also contains a wide variety of ML algorithms with the advantage that can be used without writing any program code by using a graphical user interface, making it attractive for new students in AI.

Deep learning (DL) a subset of ML, deals with deep neural networks (DNN) inspired by the biological neural networks in the human brain. The term DL was introduced in 2006, after training a DNN, by eliminating gradient vanishing during training, capable of recognizing handwritten digits with a precision of more than 98% (Le Cun et al., 2015). After this breakthrough, DL became the most researched field in AI, achieving important technological advances such as voice and facial recognition or autonomous vehicles. In the early stages of DL, the process of developing ANNs was only possible with a few tools, like MATLAB, OpenNN, and Torch, that demand high computer capabilities and tedious procedures. Today with availability and free access to modern frameworks like TensorFlow developed by the Google Brain Team, CNTK by Microsoft Research, Pytorch based on Torch, MXNet by Amazon, Keras, and ONNX by the Linux Foundation for example, the application of these methods has become simpler (Xu et al., 2021). There is a wide type of ANN such as deep neural networks (DNNs) including convolutional neural networks (CNNs), recurrent neural networks (RNNs), and long short-term memory (LSTM), and in recent development of liquid neural networks (LNN).

The origins of computer vision (CV) can be traced back to the 1960s, were the first attempts to imitate human vision by the human sensory system (cameras) and human cognitive systems (machine perception). The common pipeline of CV starts with the image or video acquisition, followed by image preprocessing which prepares the data for analysis and concludes with standardization, color transformation, binarization, and thresholding. Fernandez et al. (2020) presented a complete overview of the current applications of CV in the field of animal science. Traditional CV techniques like scale invariant feature transform (SIFT) or speed up robust features (SURF) are usually combined with ML algorithms (SVM, KNN). The DL can be defined to be a tool for CV, their combination has achieved enormous progress (O'Mahony et al., 2020).

Examples of machine learning, deep learning, and computer vision in livestock farming

An example of the use of ML is demonstrated by Chen et al. (2022), where they compare several ML algorithms to predict the excretion of nitrogen in the manure of dairy cows. The use of ML in precision livestock farming was reviewed by Garcia et al. (2020). A systematic literature review (Cockburn, 2020) of the application of ML models in cattle farming confirms that ML has become a ubiquitous tool in various aspects of dairy farming, particularly to predict data with the most used models including SVM, KNN, and artificial neural networks (ANNs). However, the majority of tested algorithms have yet to be refined for practical use.

A review (Mahmud et al., 2021) on the current state of DL in cattle highlighted two main DL algorithms: combining image processing and DL and fine-tuning pre-trained DL models. The main challenges associated with DL in the dairy sector include image quality, data processing speed, dataset size, redundant information, and cattle movement during data acquisition. We anticipate increased interest in automated cattle farming using cutting-edge DL models while acknowledging their real-time implementation requires addressing the current challenges and further improvements.

Recent CV system adoption in livestock applications has shown promising results, demonstrating their potential for high-throughput phenotyping. These systems offer real-time, non-invasive, and precise predictions for health, welfare, nutrition, and reproduction at both group and individual levels (Fernandez et al., 2020; Oliveira et al., 2021). CV applications are a burgeoning topic in dairy farming and some commercial products are already on the market. Nevertheless, there are still hurdles that must be overcome through continued research to create independent solutions that can provide vital information.

Innovation systems: application pathways of AI at the farm level

To fully obtain the main opportunities and advantages coming from AI applied in the day-to-day at the dairy farm, several actions need to allow the natural coevolution of science, technology, and production. This will depend on the innovative systems that vary among countries but usually interact between them as proposed by Pugliese et al. (2019) in a multilayered space of innovation activities. The conceptual framework of the national innovation systems, suggests that the main goal of the research is innovation (Figure 2). The first step depends on the knowledge infrastructure that is composed of three research sectors: university, government, and industry. The second step is transforming the knowledge into utility, by established companies or new startups, taking the knowledge, and transforming it into applied technologies. The introduction of a new product or service into the market interacts with customers as the third step. Usually, these types of companies are transnational conglomerates that are searching for profits on a new product of interest (Sena et al., 2021).

Geopolitical implications of AI

Several countries have classified AI as a matter of national security, this is mainly due to the potential impact of AI on the military, cybersecurity, and economics. It is estimated that the global investment in AI could reach $200 billion by 2025 which is almost double the $94 billion invested in 2021 (Goldman Sachs, 2023). Two countries are leading the technological race in AI, China, and the United States. China introduced the "Next Generation AI Development Plan" in 2017 intending to become the global AI innovation center. Based on Freeman's hypothesis, Lundvall and Rikap (2022), suggested that the emergence of a radically new technology like AI, can reconfigure the world order, and explore in depth how crucial is AI for China. The EU also launched its initiative "AI for Europe" in 2018, intending to become a world leader in this technology. The US in 2018 created the "National Security Commission on Artificial Intelligence" to evaluate the current status of the US in the field of IA, with the conclusion that the US is not prepared to defend or compete in the era of AI. Also, other countries (like Japan, South Korea, India, Israel, Singapore, and Taiwan) have the intention of becoming leaders in the AI race (Schmidt et al., 2021). This wave of interest in AI on a global scale, not only benefits non-agri-food sectors, but is also an opportunity for the expansion of AI on Dairy 4.0. Firstly, they signify resources for research, which consequently represent more tools such as AI algorithms, which can be used by researchers to solve specific problems in the dairy industry.

One potential risk is the over-reliance on one/limited companies and/or countries/regions for the provision of technology and materials for their construction, as experienced previously with the semiconductors during the COVID-19 pandemic (TSMC, Taiwan) (Michael, 2023). Under this scenario some concerns need to be considered, such as how susceptible dairy farmers using AI will be in geopolitical conflicts and changes in the global control of the distribution of certain resources; for example, data analysis has been done on servers located outside their country.

Legal and ethical concerns related to AI

Although the field of AI had remained unregulated worldwide, the EU was the first to propose the "AI Act" in 2021, reaching a political agreement in 2023, and on the way to becoming an EU law between 2024 and 2026 (Madiega and Chahri, 2023). These initiatives aim to classify and regulate the providers of AI, based on their risk, mainly to protect the consumer's rights (i.e. facial recognition in public spaces) and a special emphasis on generative AI (ChatGPT) related to transparency requirements. Also, the US president in 2023 issued an "Executive order on the safe, secure and trustworthy development and use of AI". These regulations aimed to due to the concerns on fraud, discrimination, bias, and disinformation.

Although these initiatives have been issued, none of them contemplate the agri-food sectors directly and it is still unclear how they will be implemented in non-agri-food sectors. De Baerdemaeker J (2023), presented a study at the request of the European Parliament Parliamentary Research Services were describes the applications, risks, and impacts on agri-food areas. This study identifies AI as a key technology for modern agriculture, among the concerns identified is to clarify the ownership and the exploitation of the data generated by sensors in farms, the potential risks of automation and robotics and ensure that they are safe and secure for the animals and farmers, also proposed support for protecting the investment of the farmers in AI technologies.

In the case of regulations-related challenges do not seem to currently influence the dairy sector but it is likely that in the future the launch of new regulations may affect how AI is implemented on dairy farms (De Baerdemaeker J, 2023).

Leading countries and trends in dairy AI research

In recent years, there has been an exponential growth in the number of scientific publications dealing with AI and dairy cows. The first publications started to appear in the mid-90s (Nielen et al., 1995). Several reviews have explored the geographic location, technology employed, and areas of dairy science (i.e., nutrition, reproduction, and health) (Cockburn, 2020; Mahmud et al., 2021; Shine and Murphy, 2022; Hassoun et al., 2023). Of the 4 literature reviews revised, 2 trends in geographic locations were identified based on their results (i) Cockburn (2020) and Shine and Murphy (2022), finding the major number of publications coming from the United States and Ireland, (ii) Mahmud et al. (2021) and Hassoun et al. (2023) reported the greatest number of publications coming from China as a great advantage. In general, considering the 4 reviews, other countries also stand out by their number of scientific reports like Australia, India, and the United Kingdom. The review of Shine and Murphy (2021) on AI and ML applications in dairy farming (literature between 1999 and 2021) has shown an exponential increase in publications after 2010 mostly addressing the physiology and health-related problems in dairy cows (32%) with the feature data were most often derived from sensors (48%). Also, since 2018 publications mostly employed neural network algorithms, suggesting an increasing use of DL algorithms in the dairy sector. Also, it has been found (Cockburn, 2020; Mahmud et al., 2021; Garcia et al., 2020) that AI techniques in the dairy sector were mainly applied to management, milk yield prediction, resource usage, and health and physiological monitoring (including mastitis, body condition, metabolic status, lameness, heat stress, reproduction outcomes, dystocia and calving, and feeding).

The literature, however, noted that AI algorithms failed to reliable implementation in practice, mainly due to the poor training data (Cockburn, 2020). Robotics also making its mark in dairy farming with examples such as voluntary milking systems that milk cows without being guided by humans, and laser-guided detection of teat placement for attachment of the milking unit is accomplished by algorithms that appear intelligent as well as are self-

driving vehicles to deliver feed (De Vries et al., 2023). Virtual reality is another AI application in the dairy sector, it could be employed for the training of farm workers, modeled on web-based virtual dairy herds to promote active learning of students and farmers as well as simulation and optimization models to support decision-making in dairy farms.
Furthermore, video-based monitoring systems have been suggested as a potential solution for ensuring employee compliance with farm protocols, however, these systems raise concerns among employees regarding punitive consequences, data security, and confidentiality (De Vries et al., 2023). Of note, previous studies on AI applications in dairy-related sectors lack consistent reporting of model accuracy, performance, and scalability. Most studies focus solely on model development, neglecting real-world pilots or deployments. This makes it difficult to assess practicality and applicability, as models need continuous updating and adaptation to changing circumstances.

Challenges faced by dairy science researchers related to AI

One of the main challenges that afront animal science researchers, is that AI engineering is likely not included in their training and skill development, lacking in disciplines such as mathematics, statistics, programming, big data, ML, and DL. Consequently, research students need to acquire these abilities in a short time allowance to be fully involved in all steps of an AI research project. As this is not possible on several occasions, collaborations with AI engineers or bioinformaticians for the programming process are essential, who in turn need close guidance and monitoring to understand the interpretation of AI results into biological processes. Although multidisciplinary teams offer several benefits to scientific progress, early career students and researchers may lose their interest and motivation, as they might feel less ownership of their research program and redirect their research interest to more traditional research areas such as reproduction or nutrition. This has led academic programs to incorporate courses on the topics of AI (such as programming, data science, ML, and DL) and, on many occasions, hire specialized staff.

Dairy sector's major challenges

The future of dairy farming worldwide faces several challenges, due to a growing population estimated to be 9.8 billion in 2050. In 2017, the total milk production from all dairy species (standardized to an energy-corrected milk of 4.0% fat and 3.3% protein) reached 864 million tonnes, and is estimated that in 2030 the demand will be 1,168 million tonnes, an increase of 35% in 13 years (Wyrzykowski et al., 2018). This raises the pressure on the agri-food systems to increase productivity to cover the growing demand and ensure food security. The food systems are also required to adapt to the changing climate and play a key role in reducing greenhouse gas (GHG) emissions (as a contribution to the effort of mitigating climate change), as agriculture contributes approximately 12% of the global emissions of GHG, whilst 30% of the anthropogenic methane comes from ruminants (Wijerathna-Yapa and Pathirana, 2022). Under this future scenario, the challenge for a sustainable milk production system that guarantees food safety needs to perform dramatic changes to confront these current and future challenges.

Available AI-based Dairy 4.0 products

At the dairy farm level, the applicability of AI technologies is limited to the available products on the market, that have developed user-friendly interfaces (Fifield, 2020). The great majority of these products are in the field of CV. For example, Cattle Eye Ltd. (UK; Cattle Eye, 2023) is a commercially available technology that tracks body condition scores as well as lameness indicators. Another example is Alus Feedbunk Management from Ever.Ag Ltd. allows the use of CV to monitor the feed bunk and inform the dairy farmer when supplementation of feed is needed (US; Cainthus, 2023). This type of innovation requires an inversion that comes with customer service and a complete easy-to-use interface platform. Regarding augmented reality, Nedap Livestock Management (NL; Nedap, 2023) offers a product that, through a virtual reality glass, the user can navigate through cow’s records and register daily actions, via holograms.

In the field of data-based technologies Dairy Data Warehouse has developed Predicta Guardian (NL; DDW, 2023), which recovers data from individual cows and sends it to the cloud and analyzed through AI and can predict with an advance of 60 days the presentation of transition diseases (ketosis, milk fever, displaced abomasum and retained placenta) and send an alarm to the farmer to implement corrective actions. Another example is algoMilk (SP; algoMilk, 2023) which using DL, integrates data from individual cows (such as body weight, and lactation number) and cows' production, and feed ingredients costs, to present the best solution to group cows based on their needs and optimize the ration to find the best IOFC. The major challenge that affronts data-based technologies is data integration from multiple sources (Cabrera and Fadul-Pacheco, 2021). In general, one of the inconveniences of these products is that is not clear what type of algorithms are used these are mainly due to intellectual property, on one side they declare that area using AI, ML, or DL, so is complicated to criticize the techniques used in deep.

Final Remarks

This research reflection shows a multidimensional vision, from the origins and drivers of AI, the possible impact of geopolitical factors on AI research, to actual applications in dairy systems, and future expectations. Since the third summer of AI which is the actual period, new types of AI algorithms, especially in the field of DL, are constantly reported and updated. Most of the AI applications for livestock farming are academic with little implementation for real-world settings. To change this, multidisciplinary teams should prioritize the development of efficient and cost-effective technologies, beginning with the analysis of large datasets gathered from various dairy sectors.

The speed of AI technology development requires dairy scientists to know technological tools, and the relevant skills to apply them at the dairy farm level. In the short term, the authors of this research reflection believe that AI can be a “game-changer” only if AI is integrated with other components of Dairy 4.0 such as robotics and is fully adopted by dairy farmers. The biggest opportunities in the short- to mid-term are on the integrated tools based on DL and CV, rather than in decision support systems based on data and AI. This is due to challenges around data integration from multiple sensors but for now, the storage of data is the most grown aspect. Today the dairy sector is limited to available AI products in the market, and more companies will be launching new ready-to-use AI-based products for dairy farmers within the next few years. The survival of these new startups in the early stages will be dependent on the performance of their products and their ability to co-develop together with dairy farmers so that they meet their requirements and gain their trust.

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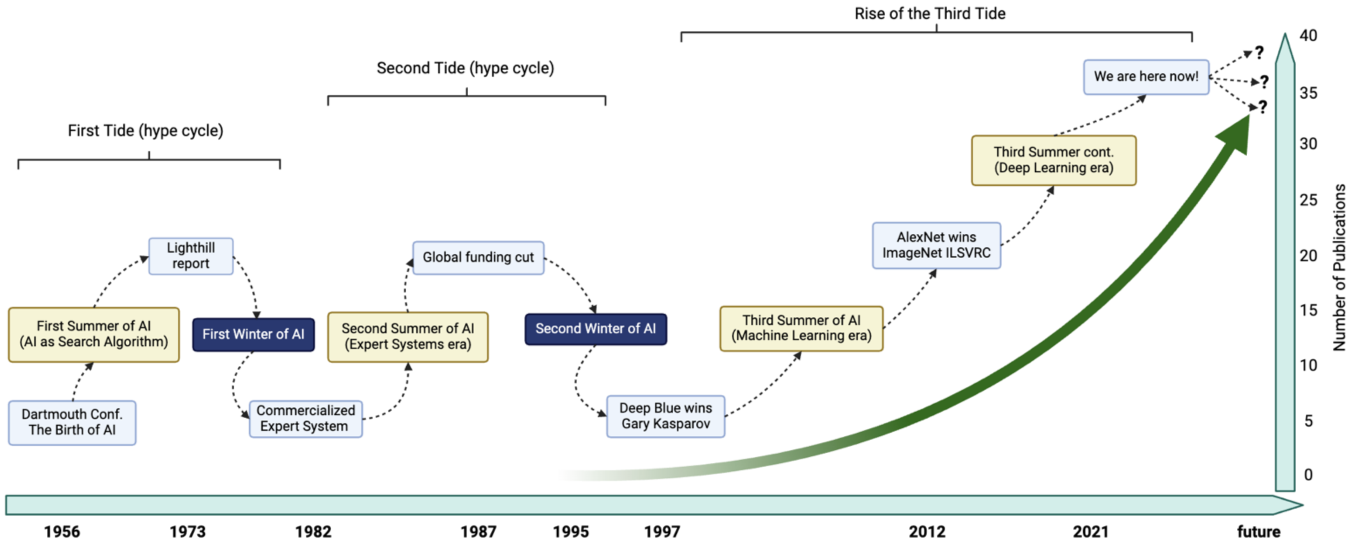
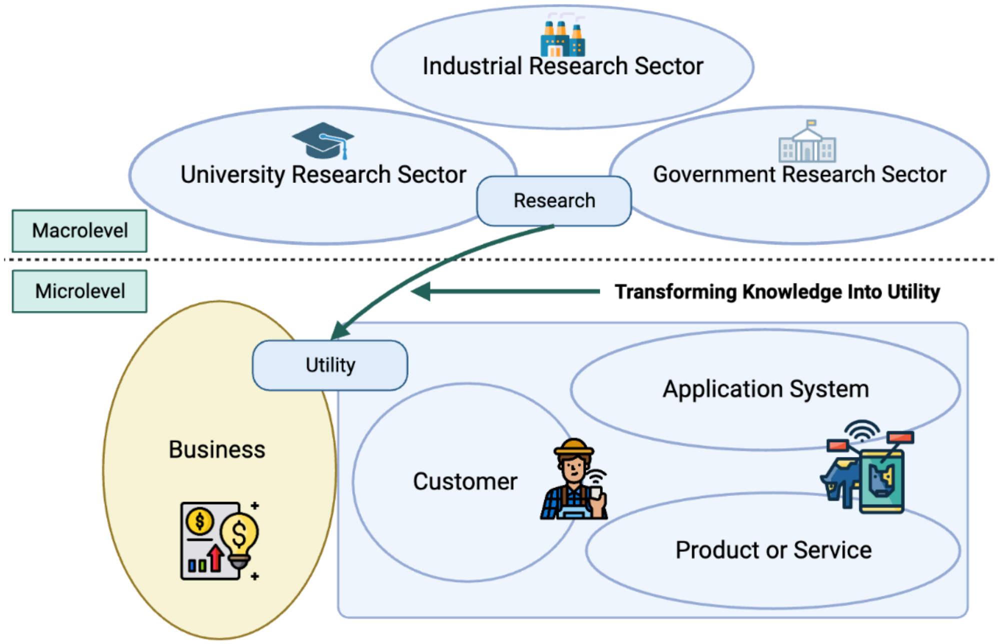


Figure 1. Cycles of development in the field of AI and the number of publications (green arrow) in dairy (Toosi et al., 2021; Hassoun et al., 2023).



487 **Figure 2.** Components of the Innovative Systems, adapted from Betz et al. (2016).