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Can Livestock Farming Benefit from Industry 4.0 Technology? Evidence from Recent Study

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Abstract: The term "Agriculture 4.0" emerged from the term "Industry 4.0" like amany other "4.0" terms. However, are Industry 4.0 technologies and concepts really applicable to agriculture? Are the benefits that Industry 4.0 brings to industrial use cases transferable to livestock farming? This paper tries to answer this question for the three dominant sectors of livestock farming in Central Europe and Germany: Poultry, pig fattening, and dairy farming. These sectors are analyzed along with the eight most relevant Industry 4.0 benefits. The results show that only part of the Industry 4.0 benefits are relevant for livestock farming in a similar manner as in industrial production. Due to basic differences between industrial and livestock farming use cases, some of the benefits must be adapted. The presence of individual living animals and the strong environmental impact of livestock farming affect the role of digital individualization and demand orientation. The position of livestock farming within the value chain minimizes the need for flexibilization. The introduction and adoption of Industry 4.0 concepts and technologies may contribute significantly to transforming agriculture into something that may be called Agriculture 4.0. Technologies are indispensable for this development step, but vocational education and open-mindedness of farmers towards Industry 4.0 is essential as well.

Keywords: livestock farming; animal husbandry; Industry 4.0; Agriculture 4.0

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1. Introduction

The term Industry 4.0 stands for the vision of the fourth industrial revolution. Based on an initiative of the German Government, the "Plattform Industrie 4.0" was founded in 2013 by three German industry associations, and the term Industry 4.0 was introduced to the public at Hanover Fair 2013 [1]. The principal precondition of Industry 4.0 is a real-time capable, intelligent, horizontal and vertical network of humans, machines, objects, and ICT systems for the dynamic management of complex systems [2].

This further development of technological processes is leading to a complete restructuring of the industrial sector, which will also have an impact on agriculture. Since no standardized definition or structure is available for the term Industry 4.0, a framework has to be developed through an analysis of the literature with which the effects on agriculture can be assessed. Based on the fundamentals stated in this work, the current effects and possibilities of Industry 4.0 on livestock farming may be analyzed.

The work presented here was first motivated by the question of how far the term Agriculture 4.0 may be defined as the implementation of Industry 4.0 in agriculture. This question is part of a necessary discussion towards a common understanding of the term Agriculture 4.0. The answer to this question is beyond the scope of this article, but we want to contribute to answering it.

The specific aim of this study is to understand whether and how Industry 4.0 benefits, as they were identified as most important for industrial use cases by Bauernhansl und Schatz [3] (cf. Table 1), are applicable and beneficial in agricultural production and the agricultural value chain. The three most important areas of animal husbandry in Germany were considered in detail: poultry, pig fattening, and dairy farming.

This study brought together expert authors from the Industry 4.0 domain and from livestock farming. The livestock farming experts estimated the applicability and usefulness of the eight Industry 4.0 benefits, based on a non-systematic literature search and personal experience.

By checking the applicability and the potential of Industry 4.0 benefits to each of these three livestock farming areas, this study not only resulted in an in-depth look at the status and potential of the application of 4.0 technologies and concepts in animal husbandry. The study also helped to understand the limits and necessary adoptions when transferring the Industry 4.0 idea to livestock farming. Thus, this study contributes to the general discussion on how far the real role of Industry 4.0 in livestock farming may justify the attribute "4.0" in the terms Livestock Farming 4.0 and Agriculture 4.0.

The primary regional focus of the study was Central Europe, with a particular focus on Germany.

This article is organized as follows: Section 2 mentions the most relevant literature and the context of this study. In Section 3, Approach of Investigation, the explanation of the Industry 4.0 benefits is cited, as the benefits determine the basic structure of this study. In Section 4, Results, we first present the most relevant differences between industrial and livestock production. This is followed by the results for the three livestock farming sectors, and finally a generalized view on the applicability, state, and potential of Industry 4.0 benefits in livestock farming. The article ends with a Discussion and Conclusion.

At the end of the paper, we conclude that, with certain adaptations, most of the Industry 4.0 benefits are applicable to livestock farming and may contribute to improving livestock production.

2. Literature

Basic constitutive elements of Industry 4.0 have been introduced before 2013, like the Internet of Things (IOT) [4], Cyber-Physical Systems (CPS) [5], Digital Twins [6], Internet of Services (IoS) [7], Cloud Computing [8].

There is no commonly accepted explicit definition of Industry 4.0, but many experts have tried to give their own definition. Herman et al. define Industry 4.0 as a "collective term for technologies and concepts of value chain organization", and they concretize their definition with a technical view: "Within the modular structured Smart Factories of Industrie 4.0, CPS monitor physical processes, create a virtual copy of the physical world, and make decentralized decisions. Over the IoT, CPS communicate and cooperate with each other and humans in real time. Via the IoS, both internal and cross-organizational services are offered and utilized by participants of the value chain" [9].

Bauernhansl and Schatz looked beyond the Industry 4.0 technologies and addressed eight areas of benefit of industry 4.0 which may be used in the definition of business model scenarios (Table 1) [3].

Table 1. Industry 4.0 areas of benefit. (Adapted with permission from [3]. Copyright 2015 Fraunhofer IPA/Wieselhuber).

Industry 4.0 Benefit
• Digital individualization ("lot size 1") • Flexibilization • Demand orientation/"X as a Service" • Sustainability • Consistent Process orientation • Automated knowledge and learning • Collaboration competence • Productivity optimization

The Plattform's 2030 vision of Industry 4.0 focuses on autonomy (in the sense of sovereignty), interoperability, and sustainability [10,11]. In view of this, Industry 4.0 might also be of some relevance for agricultural production. The transfer of Industry 4.0 technologies and concepts to agriculture has been discussed since about 2018. Braun et al. postulated that methods of the Industry 4.0 portfolio appear suitable for agricultural supply chains. They showed that Industry 4.0 concepts affect all levels in the management hierarchy and offer new opportunities for collaboration and digital communication with all partners in the supply chain, including the consumer [12]. Zambon et al. focused on the virtualization of the agri-food supply chain and on the farm management system that has a virtual representation of the supply chain and interfaces to the real world [13]. Liu et al. presented comprehensive scientific literature related to Industry 4.0 and agriculture up to 2020 [14]. They call the IoT in agriculture a "space–air–ground–undersurface integrated network (SAGUIN)", which extends the previously introduced term "space–air–ground integrated network (SAGIN)" [15]. The Association of German Engineers (VDI) has presented a status report about the state of Industry 4.0 technologies in agriculture [16]. That status report illustrated the big difference between the preconditions of industrial and agricultural production. The status report concluded that many Industry 4.0 concepts may be applied or adapted to agriculture, but today, even digitized production processes in crop production and animal husbandry are hardly digitally interconnected. Therefore, even with the principal condition of Industry 4.0, digital interconnection is still widely missing in agriculture. Bernhard et al. [17] investigated the state and potential of Industry 4.0 in agriculture by transferring the most important Industry 4.0 benefits to selected agricultural use cases. Their work contains only short, summarized statements for livestock farming. In the study presented here, this approach was further elaborated through an in-depth look into the three predominant livestock farming sectors of Europe and a more in-depth discussion of whether and how to transfer these benefits from industrial to livestock farming use cases. The motivation for this in-depth examination was more evidence and a better understanding of Industry 4.0 benefits in livestock farming.

Care must be taken when it comes to the term **Agriculture 4.0**. The establishment of the term Industry 4.0 inspired the emergence of the term Agriculture 4.0 or Farming 4.0 [13,14]. Manufacturers of farm equipment and software, service providers, and others started early to advertise their products with the term Agriculture 4.0 or Farming 4.0, meaning something like digitalization in agriculture and smart farming, without connecting to Industry 4.0 ideas [18]. In recent years, science also started to treat the term Agriculture 4.0 as inspired by Industry 4.0 [13,14].

The potential of transferring Industry 4.0 ideas and concepts to agriculture goes far beyond digitalization and smart farming. Nevertheless, we want to point out that the introduction of Industry 4.0 technologies and concepts does not necessarily constitute a historical revolution of agricultural production, justifying the term Agriculture 4.0. Unlike in industry, there is no widely accepted characterization of previous development stages called Agriculture 1.0, Agriculture 2.0, or Agriculture 3.0. The next generation of agriculture may be defined by substantial modifications other than the introduction of

Industry 4.0 technologies and concepts. The next development stage in agriculture, and the term Agriculture 4.0, may be characterized by an ecological or social point of view [19]. Even alternative landless methods like algae or artificial meat production may be brought together with the term Agriculture 4.0 [20].

Currently, it can be observed that another approach is developing out of Industry 4.0. As described, Industry 4.0 is very technologically oriented. This results in a new approach, Industry 5.0, which puts the focus back on people and their needs for sustainability and resilience [21]. This is particularly interesting for agriculture, as there is a close link between the environment, technology, and people [22–24].

3. Approach of Investigation

This study is a follow-up work of [16,17], following the same transdisciplinary approach, but with a focused and deeper look into livestock farming.

As a preliminary step, we described the most relevant differences between industrial production and livestock farming with respect to the concepts of Industry 4.0. There are: (a) the economic structure of the livestock sectors, (b) the social situation, (c) the strong environmental context, and (d) the constituent existence of living animals on the farm to be the indispensable context when comparing industry and livestock farming. Sections (b), (c), and (d) were worked out in two focused discussion meetings of most of the authors.

We then had a deep look into three different sectors of animal production:

1. Poultry (broiler and layer production systems)
2. Pig fattening
3. Dairy farming

For each of these sectors we proceeded in three steps: First, we gave a very short introduction to the specific economic situation of the sector, we summarized the state of digitalization in the processes and farms, including sensors, autonomous machines, network and communication, software, and data. In the third step, for each of the sectors, we detailed and discussed the applicability, state, and potential of the eight possible benefits of Industry 4.0 that were elaborated by Bauernhansl and others as basics for the development of Industry 4.0-oriented business models [3,25].

The third step was realized by one or two coauthors per livestock farming sector with extensive expertise about digitalization in the respective sector. For each of the eight Industry 4.0 benefits, the coauthors were requested to estimate the applicability of the benefit to livestock production and to demonstrate the state and potential by selected technologies and applications. The statements were elaborated based on related literature, on own experience, and on personal communication with farmers, manufacturers, and other partners in the value chain. The research method of asking only one or two experts for each sector was chosen due to the need of prior basic understanding of Industry 4.0 and the meaning of the benefits. Instead of taking interviews with the experts, they were asked to work out written statements, referring to related literature. This approach must be regarded as a limitation of the study.

For a good understanding of the eight benefits (Table 1), we recall the short explanations given by Bernhardt et al. [17]:

Digital individualization: Digital media considerably simplify the offer of individualized products and services ("lot size 1"). This includes the entire production chain from customer request to realization.

Flexibilization: Industry 4.0 offers the possibility to react quickly to fluctuations in demand by making production capacities more easily scalable (e.g., through more intelligent plants and simplified capacity procurement) and by making more data available about the environment and the company itself.

Demand orientation/"X-as a service": Service orientation will be transferred to business models, which in turn will be facilitated by increasing data volume and flexibility. For example, products and services can be offered and billed according to the extent of use.

Sustainability: Better planning and control of production processes through digitalization can save resources, e.g., through cost- and load-optimized production programs for energy-intensive processes. The availability of extensive and timely data from production and the supply chain allows an additional reduction in resource requirements, e.g., through the early detection of quality problems. In the case of animal husbandry, we have to consider the environment and socio-economics as dimensions of sustainability, and also animal health and welfare are important aspects of sustainability.

Consistent process orientation: The networking capability enables each value-added stage in the supply chain (internal and external to the company) to retrieve information on the overall process. This enables a customer- and employee-oriented work organization.

Automated knowledge and learning: The increase in data volume and the degree of automation in Industry 4.0 environments prove to be ideal prerequisites for the use of self-learning functionalities. The data can come from outside the company boundaries, for example through IoT approaches. In addition, the systems in question enable extended and simplified knowledge management in companies.

Collaboration competence: In terms of end-to-end process optimization, Industry 4.0 approaches reduce the necessary effort for cooperation between value-added partners. For example, it is possible to know the current stock and available capacity of suppliers.

Productivity optimization: All the above-mentioned implementation options contribute to an increase in productivity. Optimization options can be found at various levels, from the strategic orientation of the company to the operational management of production processes.

4. Results

Both, industrial production and livestock farming take place in buildings. Nevertheless, there are fundamental differences between the production preconditions that affect the business use cases. Before investigating individual livestock farming sectors, a look onto the most relevant differences between livestock farming and industrial production is necessary.

4.1. Livestock Farming vs. Industrial Production

This work identified four predominant differences between the preconditions of livestock farming and industrial production: First, the overall structure of the sector, second, the social situation in agriculture, third, the environmental context, and fourth, the presence of living animals.

4.1.1. Structural Characterization of Livestock Farming in the European Union and in Germany

EU farms can be broadly characterized as either (i) semi-subsistence (ii) small and medium-sized farms or (iii) large agricultural enterprises [26]:

Of the EU-27′s (Year 2020, without UK) 10.3 million farms, 4.0 million had an economic size in terms of standard output below EUR 2000 per year and were responsible for only 0.9% of the EU's total agricultural economic output. These very small farms are at the (semi-)subsistence end of the farming scale; about three quarters of such farms in the EU consumed more than one half of their own production.

A further 3.0 million farms had an economic output within the range of 2000–8000 EUR per year. Together, these very small and small farms accounted for two thirds (68.3%) of all farms in the EU in 2016 but were responsible for only 4.6% the EU's total agricultural economic output.

By contrast, the largest 278,000 farms (2.7% of the EU total) each produced a standard output of EUR 250,000 per year or more in 2016 and were responsible for a majority (54.4%) of the EU's total agricultural economic output; these farms can be characterized as being large agricultural enterprises.

Consequently, the livestock sector in Europe is characterized by a high diversity in production systems, intensity, and farm size.

In Germany, the structure of farming and rural life has changed substantially during the last 70 years. In 2020, the German government constituted the "commission on the future of agriculture" with 32 representatives of "the full range of societal groups relevant to the agricultural policy with the involvement of the scientific community" and the task of "drawing up recommendations and proposals to ensure that agriculture in Germany is environmentally, economically, and socially sustainable into the future." [27]. In its final report, the commission summarizes the structural situation of German agriculture as follows: Agriculture in Germany has a broad range of different farm structures. This primarily reflects great variation in natural conditions from region to region but also differences in other conditions for agricultural production including socio-structural patterns (such as urban versus rural), economic factors (such as industrialization), and historical influences (such as inheritance law). There are thus major regional differences between the southwest of Germany, where farms are mostly small, and the north and east of Germany, where large farms predominate [27].

4.1.2. Social Situation in Agriculture

Due to the capital and owners structure in Germany, predominantly in the southwest, unpaid family workers compose at least part of the workforce on 95% of farms in Germany [27]. Based on 2016 data, family labor is the prevalent labor force on the basis of full-time equivalents. The 2016 figures were 55% family labor, 34% permanent non-family labor, and 11% seasonal labor for the total agricultural sector.

In small, family-operated farms, the degree of labor division and specialization is very low. All tasks are fulfilled by a small number of persons. The fraction of manual labor is high. Even in such small farms, digitalization has great potential in simplifying work, increasing flexibility, and providing specialized knowledge and decision support on a high professional level. On the other hand, the labor organization of large livestock farm companies is similar to industrial labor organization. The employees are performing highly specialized tasks in schedulable working shifts; also, the machinery is highly specialized and allows high throughput.

4.1.3. The Environmental Context

Most livestock live in animal houses. Some of these buildings may look similar to industrial factories. However, livestock farming is much more related to environment and nature than every industrial production. Food must be produced on fields and grassland with their indissoluble interconnection and interaction with nature and environment. The animal welfare and productivity depend, e.g., on food quality, weather, and natural illumination, as long as the natural environment is not replaced totally by an artificial climate and light regime. Livestock farming is a big emitter of greenhouse gases, mainly methane (mostly emitted by ruminants) and ammonia.

As a result of livestock farming, big amounts of manure and other organic residues must be applied as farm fertilizer in a sustainable circular economy. Since livestock production is strongly concentrated in some European regions, local surpluses in slurry are a big challenge, threatening potable water and groundwater.

The livestock density index gives an indication of the pressure that livestock farming places on the environment. In 2016, the livestock density in the EU-28 reached 0.8 livestock units (LSU) per hectare of utilized agricultural area (UAA, Table 2). The grazing livestock density index gives an indication of the environmental pressure of livestock grazing on fodder area, which consists of fodder crops grown on arable land as well as permanent grassland. The livestock counted as grazing animals are cattle, sheep, goats and equids (horses, donkeys, and other members of the horse family). For the EU-28 as a whole, the grazing livestock density in 2016 remained at 1.0 LSU of grazing livestock per hectare of fodder area.

Table 2. Key figures of agricultural structure and livestock farming in the EU and in Germany. (LSU: Livestock units).

	EU-28	Germany
Total number of farm holdings	10.3 million [a]	263.500 [b]
Number of holdings keeping livestock	5.7 million [a]	167.900 [b]
Utilized agricultural area (UAA)	156.7 million ha [a]	16.6 million ha [b]
Average farm size in hectares	15.2 ha	63.0 ha
Poultry population in livestock units	20.8 million LSU [a]	2.2 million LSU [a]
Pig population in livestock units	33.0 million LSU [a]	6.5 million LSU [a]
Cattle population in livestock units	64.3 million LSU [a]	9.0 million LSU [a]
Livestock density index	0.8 LSU/ha [a]	1.1 LSU/ha [a]

[a] Eurostat, data for 2016 [26,28,29]. [b] Destatis, data for 2020 [30].

Out of the total GHG emissions in 2019, around 10% was emitted by the agricultural source sector. Over the time span 1990 to 2019, the source sector reduced its emissions by 102 million tons of CO2-equivalent, which corresponds to −21% compared with 1990. Emissions from enteric fermentation (methane), the fermentation of feed during the digestive processes of animals, were reduced by 47 million tons of CO2 equivalent or 22% of the 1990 GHG emissions. The largest share of the GHG emissions due to enteric fermentation, 86%, are from the digestive system of cattle. These emissions fell by 21% over 29 years, but the decrease in GHG emissions primarily took place during the first decade.

In 2018, agriculture accounted for 93% of ammonia emissions in the EU-28. Emissions of NH3 are not declining at the same pace as the other main pollutants. Twelve countries have focused more than a quarter of their policies and measures (PaMs) on reducing emissions from agriculture, and 60% of the PaMs focused on the agricultural sector, anticipating the establishment or further development of a national advisory code of good agriculture practice [31].

The impact of livestock on the environment is an important topic of discussion in society. The concept of planetary boundaries [32] was a basis for the report "less is more" published by GREENPEACE in March 2018 [33] and the report of the RISE Foundation in autumn 2018 [34]. Both reports conclude that the number of animals kept for food production must be greatly reduced globally and in the EU in order to stay within planetary boundaries. Technological progress in livestock systems can increase the production efficiency, the wellbeing of farm animals and decrease the environmental impact. The Industry 4.0 measures as advanced production methods may be helpful innovations to bring the livestock sector within the boundaries.

4.1.4. Living Individuals: Animals and Humans on the Farm

Living animals present the most obvious and relevant difference between industrial production and livestock farming. They are vertebrates with eyes, voice, senses, and perception, with brains and emotions. Every human working in livestock farming feels an emotional relation to the animals, and the animals are protected by law and culture from mistreatment and negligence. Not only the working people on the farm but also the public society and the consumer expects and requires that animals are treated with respect to their biological requirements and with a certain level of animal welfare.

Domestic animals not only interact with the humans in their environment but also with the technical infrastructure and machinery [16]. The total system is characterized by a complex interaction of humans, animals, technical facilities, and the environment. Biological rhythms and processes are the driver and impulse generator for part of the activities and tasks. Each individual grows differently, has its own need of feed, water, climate, movement, sexual behavior, and so on. Each individual may be different in susceptibility to stress and diseases. Autonomous machinery must be able to react to the needs and behavior of the animal.

Industry 4.0 benefits are driven by industrial use cases that allow the production of individual products and services as requested by each client. In biology, the term "individual" has two different meanings: "(1) in general: the individual living being in its specificity; above all, the individual being in its uniqueness in contrast to the mass (mass society). Individuality means the differentiation of the individual from the set of individuals. . . . (2) a spatially and temporally limited structure of certain shape, organization and possibilities for change." [35]. When applying the benefits "Digital individualization" and "Demand orientation" to livestock farming, these benefits must regard not only the client demand but also the challenge to cope with the specific identity and demand of each individual animal, or at least each group or herd of animals.

4.2. Poultry

The German egg production of approx. 14.3 million eggs p.a. (2020) covers only 72% of the national consumption. About 10 million eggs p.a. must be imported; about 75% of the imported eggs originate from the Netherlands [36]. There are about 47,100 registered egg producing farms, but 84% of these producers have less than 100 laying hens. Only about 2000 farms have more than 3000 laying hens with a total of 43 million hens in 2020. Farms with 10,000 to 30,000 hens are the most common size; about 30 farms have more than 200,000 laying hens.

The German sector of broiler fattening counts only 3828 farms (2020). In total, 99% of the broilers are produced in 1378 farms with more than 10,000 broilers per farm, and the production is strongly concentrated, with more than half of the broilers being produced in Lower Saxony [37].

4.2.1. State of Digitalization of the Poultry Sector

Digitally supported systems have found their way into poultry farming for many years now. The decreased availability of agricultural workforce and the development to more large-scale enterprises promoted the entrance of digital systems into poultry husbandry. The use of automated feeding and weighing systems and their control via the barn computer are established supporting systems in the husbandry systems. Depending on the system, so-called egg belts and also manure belts are installed in laying hen and breeder housing, which contribute to the automation of recurring processes. Sensor-supported systems can be found as standard in the area of climate control in poultry houses [38].

The methods used so far are mainly summarized under the term Precision Livestock Farming. The increasing use of smartphone technology and the real-time transmission of barn and herd data is becoming apparent and can provide the herd manager with support in making timely decisions on controlling stock processes and checking the success of measures [39]. This no longer only includes ensuring animal health but also animal welfare. In addition to the use of proven sensor technology, digitally supported, audio-visual systems can also provide support for this in the future [39,40]. Nevertheless, all systems support human decisions but do not substitute human knowledge and skills.

Networking different data should definitely contribute to an improvement in the barn climate. Different interfaces should not pose a barrier here. The possibility of connecting to the internet in the stables is problematic. Alternatively, many manufacturers offer a digital barn card, which can usually only be used in-house.

Broiler production typically happens within a well-organized food chain production system. Digital data exchange along the value chain is already common in part of the sector.

4.2.2. State and Potential of Industry 4.0 Benefits

Digital individualization: As a prerequisite for high stock health and the demand-oriented supply of poultry, husbandry is operated in a continuous in–out process as standard where a herd represents an age group. An individual animal identifier, for example by wing marks, is not used outside of breeding populations or for research purposes. Instead of relating detected events to individual animals, single animal events are detected anonymously and combined to derive conclusions on the herd level. By specifying expectation corridors for various animal-related data such as the development of live weight with scatter parameters, feed and water consumption, and mortality, conclusions can be drawn about the health of the herd on the herd level. A regular evaluation of the herd data with scatter, which is required in addition to the documentation, allows an early detection of abnormalities or deviations from the target.

An animal-related, digitally supported recording via imaging systems takes place at the slaughterhouse to classify the carcasses or to identify and evaluate breast skin changes and footpad changes (e.g., systems from Meyn and CLK). This recording not only provides the assessment with regard to marketing (yes/no; whole body/part) but also allows some retrospective evaluation of the husbandry.

Flexibilization: Flexibility is possible at the operational level regarding the time of removing the flock. For example, by linking data such as mortality, live weight, and feed consumption in the Farm Management System, a very good estimate of the data for the slaughter weight is made possible. From this, the loading date can be flexibly brought forward or set back by days in order to be as close as possible to the carcass requirements and thus to the sale product for retailers. Nevertheless, flexibility is limited due to the constant occupancy of the barn and correlated lead time for, e.g., hatchery and processing.

Information transparency: Due to the strong vertical integration within poultry farming, there is, depending on the company, transparent data management across the value chain of broiler chickens and laying hens. Developing and establishing a system to promote the use of data while at the same time protecting transparency is part of ongoing research projects such as "5G Agrar" as part of digitalization in agriculture in the state of Lower Saxony (Zukunftslabor Agrar within ZDIN [41]). The linking of different systems with different interfaces as well as the transparency of inventory data within the chain is currently handled with caution due to the risk of data misuse. However, work is being undertaken on this because it represents the essential basis for risk-oriented inventory management and significantly contributes to improving animal health and animal welfare.

Demand orientation/"X as a Service": An exchange of digitally supported systems between farms does not take place, on the one hand against the background of biosecurity, but also because they are permanently installed in the stable building. Future procedures such as hatching in the barn for fattening poultry could offer another way here, since this event only takes place in a narrow time window at the beginning of the husbandry period.

The demand-based recording of the housing environment via the sensor-based recording of the litter (e.g., temperature, pH value, water content) requires the continuous use and permanent installation of sensors in the data collection chain.

Sustainability: Sustainability in poultry farming in terms of resource optimization is promoted by the correct application of digitally supported systems. Digital and sensor-based systems offer the potential to support risk-oriented herd management. This still requires the specialist skills of employees but can compensate for the shortage of workers in the areas of manure removal and biosecurity (e.g., manure belts and disinfection robots) as well as daily work such as egg collection (egg belts) [42–44]. Automated de-stalling, as is now partly used in broiler chicken and turkey stocks (e.g., Chicken Cat) and has also been tried and tested as an animal-friendly process, shows a reduced use of labor or is less physically demanding [45,46]. Correct and precise sensor technology can significantly contribute to needs-based husbandry by recognizing the smallest deviations and thus also promotes the protection of resources (reduction in "surplus").

The future increased use of organic material to fulfill species-specific behavior and to promote well-being must be seen in the sense of improving animal welfare and induces a reduction in the risk of behavioral disorders and the promotion of animal health.

Consistent process orientation: Poultry farming with the production of egg and meat products is extremely process-oriented. However, vertical integration in particular enables networking from the hatchery to the slaughterhouse in terms of risk-oriented inventory management and production. This also includes the veterinary care of the stock, the production of feed, and the production and use of additional materials such as bedding and employment materials. In the future, this will play a significantly greater role, also in terms of process assurance, and can be promoted by smart technology and AI [44].

Automated knowledge and learning: With the use of imaging systems such as camera-based systems for detecting plumage damage [47,48], behavioral disorders should be recognized early in the future and corresponding risk factors should be derived [49–51]. New technology such as augmented reality gives the opportunity to compare actual behavior and predicted behavior in order to improve the understanding of single events and to adapt management decisions [52]. So far, these systems are being tested at the research level and offer great potential for ensuring an animal-friendly housing environment.

Collaboration competence and productivity optimization: In the field of sensor-based technology, there are already tried-and-tested systems such as drinking height adapted to animal size. This reduces the amount of water entering the litter and significantly improves the climate in the barn and the quality of the litter. Potential can be seen in the linking of audiovisual processes because this allows objective herd observation at times when the animal owner is not in the barn (24/7).

4.3. Pig Fattening

Germany is a net exporter of pig meat. About 11.2 million fatteners (above 50 kg) live in about 16,700 farms. (European Commission 2022) Farm sizes vary from an average of 300 to 400 fatteners in the southwest of Germany, and 38% of the fatteners are growing in farms with more than 2000 individuals. The majority of pigs are fattened in farms sized from 1000 to 2000 fatteners. In recent years, the pig population in Germany has been declining [53]. In particular, small- and medium-sized farms have been dropping out of production. [54,55]. Overall, a ten-year comparison of fattening and breeding pigs in Germany shows that the number of pigs decreased by 20.8% or 5.8 million animals since 2012, while the number of farms decreased by as much as 41.0%. One reason for this is probably the social discussion in Germany on animal husbandry [56].

The main focus of fattening pig production in Germany is in Lower Saxony and North Rhine-Westphalia with over 50%. The rest is evenly distributed across all other federal states.

Germany ranks second in the European Union behind Spain in fattening pig production. The group of the five largest producers furthermore includes France, Denmark, and the Netherlands. The development of the herds between 2020 and 2022 shows that there were moderate increases in Spain between the individual years. While a clear reduction in stocks over the three years could be observed in Germany, there was only a moderate decline in the other large producing countries.

4.3.1. State of Digitalization in the Pig Fattening Sector

Pig farming has a high degree of automation due to its clear structural, spatial, and temporal process orientation. The individual main process steps from gilt production through piglet production to fattening build directly onto each other. The individual process steps are also subdivided in such a way that, e.g., in piglet production, the individual production steps of the mating center, waiting room, and farrowing house are connected to one another in a fixed weekly rhythm.

There are many approaches to the production method in pig farming that are also present in industrial production [57].

Basically, pig farming offers good conditions for the networking of individual subsystems due to its fixed spatial and process structure [58]. Permanently installed systems for feeding and air conditioning may be connected via cable. There is little to be found in the field of animal sensor technology since there are hardly any possibilities due to the lack of sensors [59].

Because of the costs compared to the revenue opportunities, sensor technology in individual animals almost never goes beyond the research stage. Contactless sensor technology, e.g., image analysis or thermography, is also rarely used outside of research due to the high costs [60,61].

4.3.2. State and Potential of Industry 4.0 Benefits

Digital individualization: In pig farming, individualization tends to refer to a group of animals. Examples of digital individualization include the animal-specific nutrient supply of sows during on-demand feeding and the optical recording of the weight of individual animals during fattening [62,63].

In the research area, research is increasingly being carried out into digital individualization. So far, this has rarely been applied in practice, mostly for cost reasons.

Flexibilization: In its current orientation, pig farming is a rather inflexible system overall. It is a fixed-line production dependent on biological cycles.

The entire production is currently designed for large one-sided quantities. Individualization based on the individual animal does not currently take place. This production method is also a problem in the current social discussion [64]. The corresponding approaches from Industry 4.0 could help here [65].

Information transparency: In terms of the basic structure, pig production is actually predestined for comprehensive information transparency. In the individual sub-systems such as climate control and feeding, data are also recorded and used accordingly. However, so far there are no general and open data interfaces or fair rules to make the data sufficiently transparent and to share them with other systems. The first signs of certain information transparency can be seen in the salmonella monitoring between the slaughterhouse and the fattener [66]. The degree of vertical integration in this sector is varying. There are meat production chains like in poultry, organized by external services.

Demand Orientation ("X-as-a-Service"): The structure of demand-oriented provision is usually only available in the form of wage work such as cleaning stables or other things in pig farming.

Sustainability: In pig farming, concentration on certain areas with advantageous production factors can be observed. The concentration of animal stocks can have a negative impact on sustainability if the economic and ecological assessment of the individual production factors is not balanced [67].

Consistent process orientation: Pig farming is very process-oriented due to its structure. The individual production processes are strictly geared towards the production of meat.

Despite this clear process orientation in production, this continuity cannot be found in the area of data management. There is often a lack of data transfer between the individual partners in the production chain, such as the transfer of health data from piglet rearing to the fattening area. As a result, measuring points and links are not optimally recognized, which makes the use of decision models and their implementation more difficult. Industry 4.0 concepts would offer basic approaches to improve process data orientation.

Automated knowledge and learning: In the field of automated knowledge and learning, pig production offers great potential due to the relatively quickly repeated production steps in which data series are continuously generated. This knowledge is still often used in the individual production steps, but it is often missing beyond the individual production steps [68].

Collaboration skills and productivity optimization: In pig farming, the networking of different production stages would result in many approaches for Industry 4.0. For example, the growth behavior of the single piglet could provide important information for stall management in the fattening barn, or the lung and liver findings in the slaughterhouse could provide parameters for health and climate management in piglet rearing and fattening. However, there is hardly any implementation at the moment. There are already software tools available for improved data management along the value chain, such as, e.g., from the Dutch company ChainPoint B.V. Such tools may facilitate and increase digital data transfer for quality assurance.

4.4. Dairy Farming

Milk is among the key food products consumed by humans in many countries around the world. Population growth, together with an increase in income, results in the increased consumption of milk products. Similar to meat, the consumption of milk reflects national wealth. Milk is among the essential products of the agricultural market, and it is the key agricultural product for the European Union [69].

The EU produced 160.1 million tons of raw milk in 2020 [70]. With 33.2 million tons of raw milk, Germany is the biggest cow milk producer within the EU and net exporter of milk and dairy products. Milk production is the most important branch of Germany's agriculture [71]. The milk production sector is based on approx. 55,800 farms and 3.89 million dairy cows (April 2021). The number of farms with dairy cows has dropped down by 40% since 2010, but the number of cows only dropped by less than 10% at the same time [72].

In the characterization of the economic situation of dairy farms in European countries, Germany fell into cluster 5 together with France, Italy, and Belgium. The characteristic feature of this cluster was a quite high level of the assets-to-land ratio compared to other groups. This can be explained by the medium area of agricultural land accompanied by the widespread use of production machinery and a high value of fixed assets [69]. However, this classification was based on averages per country, and Germany shows an average herd size of 70 cows, a big variety by region. Average farm sizes range from 43 dairy cows in Bavaria to 246 in Mecklenburg–West Pomerania, including some farms with more than one thousand dairy cows. Farm size is used as an indicator for several characteristics, like labor input, land use, or technology level.

Owners of small farms in southern Germany often obtain part of their income from non-agricultural activity. Most of the milk production is located in regions with a high grassland percentage. Overall, 31% of German dairy cows have pasture access in the summertime and 88% live in loose housing systems [72].

Based on the European Council regulation (EC) No. 820/97, Germany has established a system for the identification and registration of bovine animals: Hi-Tier (commonly called HIT) [73]. This system was expanded gradually with additional components such as the application of pharmaceuticals and animal health management and documentation.

4.4.1. State of Digitalization in the Dairy Sector

The use of electronic devices has a long tradition in dairy farming, especially in those farms with freestall or bedded pen barns and specialized areas for feeding, milking, and resting. A good overview of the current sensor systems is given by Stachowicz and Umstätter [74]. These types of dairy barns have increasingly been used since the 1980s. The implementation of computers and sensors started at that time under changing names and aims: monitoring and control systems for dairy herds, e.g., [75,76], precision dairy farming, e.g., [77–79], or smart dairy farming, e.g., [80–82].

Automation is widespread in dairy farming, promoted by [several factors, such as] the clearly structured and recurring daily processes and the human workload in them. Most important are the Automatic Milking System (AMS), Automatic Feeding System (AFS), and automated cleaning and bedding systems. In addition, there are also multiple sensor-based analysis and decision support systems. Research and development in these topics are comparable with those in other parts of the world [83–86].

Animal identification, animal location, heat detection, calving detection, the observation of milk quality, and the monitoring of the barn climate are some areas of sensor development in combination with the use of algorithms to make dairy farming "smart".

A breakthrough in automation can be seen in the automatic milking systems that have seen increasing use since the 1990s. The individual milking process steps are automated. These include identifying the cow via an RFID chip, cleaning the udder, checking milk quality, recognizing and applying the milking cluster to the individual teats of the cow, the flow-controlled milking of the cow, removing the milking cluster, and dipping the cow. In terms of the basic structure of processing individual process steps, AMSs are comparable to machine tools in the area of Industry 3.0. The other systems in the dairy cow barn are to be judged at a similar level of technology. Overall, they offer great potential for an Industry 4.0 level in agriculture. Some of the possibilities are being considered but have not yet been strictly implemented.

Dairy farming offers good conditions for the networking of the individual systems within the farm and beyond due to its fixed spatial structure. The stable-internal networking can often take place via cables and ends in a star shape in the office. Inside the barn, this is used as a control center. Wireless networks for different sensors on the cow often cause difficulties here since there is no uniform data and radio standard, with the exception of animal identification. Energy supply is another challenge with cow sensors.

A frequently occurring (German) problem is networking with other participants in the value chain (feed, farm, processing plant) via a telecommunications provider. The data networks in rural regions are often not powerful enough to ensure direct access to data networks in dairy cow barns. Additionally, there are other aspects relevant for successfully integrated digitalization in rural areas [87,88] and for a sustainable food system [89–92].

4.4.2. State and Potential of Industry 4.0 Benefits

Digital individualization: Other than in broiler and pig fattening, cows have always been addressed and documented as individuals. More than that, in dairy production, a quarter of the udder is also a typical entity. The advantages of quarter-individual milking are described in the literature [93–97]. This type of milking is available in AMSs as well as in conventional milking parlors [98].

There are both animal-related (cow, udder quarters) and product-related (milk) approaches to individualization. A system that has been in use for a long time is the individual administration of concentrated feed via a station with the identification of the animal via a transponder. In modern software for herd management, each cow has their own data set, including all available data of the single cows. Automatic process control like in the AMS requires many more data. The guidance of the robot arm is based on the stored data of body measurements combined with online sensors finding the teats. When milking, there are also approaches to separate the milk individually for each animal and its ingredients, in order to enable individual marketing.

Decision support is currently the most intensively investigated field in the area of individual dairy health management. To identify an abnormal behavior of a single cow and combine that digital 'information' with a probably ongoing health disorder is the aim of many research activities [99]. For prognosing health events, it is well known that it leads to more sensitivity to compare the current value with the moving average of the same animal (for example, of the last 5 days) and not with the current mean of the total herd [100,101].

Flexibilization: Dairy production is a process, strongly dependent on a number of time-consuming, biological rhythms, such as growing, puberty, pregnancy, lactation, milk synthesis, or milk ejection. Consequently, flexibility from the point of process control can be organized only within these limits. Flexibility is difficult to implement with AMSs and other automated systems due to their workload and continuous use over the day and year. If the farmer is taken into account in the system, there is a high degree of flexibility. The farmer is relieved of site- and animal-related monotonous work and can devote himself to monitoring the process and animals.

The container AMS, which accompanies the cows to the pasture when they are kept on the pasture and come back to the barn in the autumn, could be seen as an approach to make grazing husbandry more flexible. At present, flexibility cannot yet be recognized as a direction of development. The focus is currently more on adaptation through individualization in individual companies.

Demand Orientation ("X-as-a-Service"): The idea of providing technology based on need is not widespread in the dairy cattle sector. The individual systems are permanently assigned to the building, and the animal stock is adapted to the technology rather than vice versa.

Only in the case of mobile feeding systems, there sometimes exists the approach that they are used and billed by several companies as required.

Sustainability: Worldwide dairy farmers are engaged to make their production systems more sustainable [89–91]. There is a copious amount of literature to improve the three pillars of sustainability. Especially in relation to the experiences with Industry 4.0 processes, dairy farming has many options for improving sustainability by adopting these. The product service system [102], as a tool for improving resource efficiency, may be one direction [103], and the integration of circularity by the design [104] of future dairy farming technologies is a further option.

Dairy farming shows that automation makes it possible to decouple the processes from the human workforce and may increase human wellbeing. This means that even small units can operate sustainably.

Sensor-based health and welfare monitoring and evaluation [105–109] will improve the quality of welfare management. Additionally, systems of environment monitoring inside and outside the dairy farm may help to reduce environmental impacts. Monitoring systems combined with decision support systems [110–114] can improve sustainability in other critical topics of dairy farming.

Consistent process orientation: Biological rhythms characterize dairy farming processes fundamentally (see above "Flexibilization"). The processes run continuously and need technical assistance from time to time. Besides the main product, milk, there are other products (calf, meat, manure) that are created in the process and need to be considered in the process management.

The structure, standardization, and documentation of dairy farming processes are typically not yet available in a (digital) way that third parties can understand or work with. This makes the use of decision models and their implementation more difficult. Industry 4.0 concepts would offer basic approaches to improve process orientation, especially along the value chain. The grand challenge is adaptation in a biological system with individuals (humans and animals) and technical entities.

In terms of its basic structure, the milk sector is predestined for comprehensive information transparency. Traditionally, in dairy production, there exists an exchange of (digital) data based on standards in the field of breeding, quality control, and performance monitoring. Technical sub-systems also use recorded data. However, so far, there is neither a general and open digital data interface within the value chain nor negotiated rules to share these data fairly [115]. Not infrequently, the different systems of one manufacturer do not have the necessary information transparency yet.

The exchange of digital data along the whole value chain of dairy production (inclusive of all by-products) opens options for new business and has much potential to improve the efficiency and sustainability of the process by recognizing and answering the long list of open questions [116].

Automated knowledge and learning: AMSs and herd management programs offer great potential for automated knowledge and learning, as animal-specific data series are continuously generated. Numerous scientific papers show the potential for automated knowledge generation through the help of algorithms [109]. The networking of various automatic systems in barns means that there are many approaches in comparison to Industry 4.0 that have so far hardly been used. For example, a measured change in the amount of milk in combination with other individual information could lead to an automatic adjustment of the feeding to individual animals. However, these data are not yet used consistently in the sense of Industry 4.0. The status of cows by law and its ethical implication brings additional challenges for the development and use of algorithms in dairy farming in the field of responsibility and trustworthiness [117,118]. To obtain data for learning and to offer management services, some companies collect the whole milking information from the AMS by connecting the system to a central server via the Internet.

Collaboration competence: Digitalization alone demands many new or improved skills by users, and the implementation of Industry 4.0 measures increases this additionally [119]. The complexity, variability, and self-organization of the biological sub-processes in combination with a whole value chain management demands new qualifications for everybody working in this field. Successful cooperation demands at first a common language. Digitally assisted or autonomously managed dairy production demands not only improved skills within the farms and along the value chain but by all related enterprises and institutions surrounding them as well.

Productivity optimization: As stated above, there are many points visible for improving the productivity of dairy production in the context of the reduction in environmental loads and the improvement of sustainability and animal welfare. Thus, the productivity improvement of dairy production must be organized in recognition of the multiple expectations of society. In view of the importance and transformative benefits of AI as well as its risks, AI is a growing policy priority for all stakeholders, and trustworthy AI is the key to reaping AI's benefits [120]. According to the ethics guidelines for trustworthy AI [121], a sector-specific application of these guidelines seems recommended [122].

4.5. Generalized View on the Applicability, State, and Potential of Industry 4.0 Benefits in Livestock Farming

The investigation of the state and potential of Industry 4.0 benefits in poultry, pig fattening, and dairy farming showed many commonalities, even if there are differences between vertically oriented sectors like broiler and pig fattening and the more horizontally oriented dairy farming. Some Industry 4.0 benefits offer the potential for the further development of livestock farming to generation 4.0. A few Industry 4.0 benefits need to be redefined for livestock farming or are not really required (Figure 1).

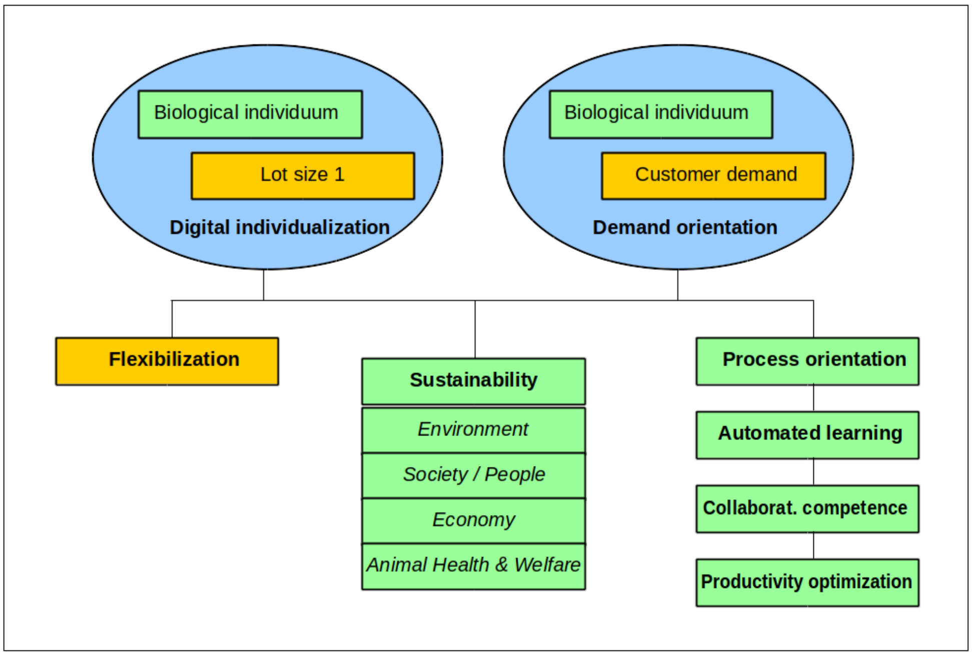

Figure 1. Applicability and potential of Industry 4.0 benefits for livestock farming, as far as the main products are not sold directly to the consumer but to the food industry. Other than in industry, individualization and demand are mainly directed towards the biological individuum. Green: Potential Industry 4.0 benefit for livestock farming. Orange: Rarely applicable and little needed in livestock farming.

The main part of livestock products is sold to the food-producing sector. In most cases, this sector requests homogenous product and quality parameters over time. The demand in terms of quantity may change over time. However, basically, continuous high-throughput farming is necessary for economic success in a very competitive market.

As a consequence, varying small product quantities with individual customer-defined features (“lot size 1”) are not needed in agricultural production. Additionally, there are typically no changes in the product features that are requested by the customer. Thus, the livestock production system became very rigid and inflexible. Sure, there are some minor options for flexibilization and demand orientation, such as changing the animal race, the food composition, a certain variability in the slaughtering weight, or the hatching date, but they have less importance than in industry.

On the other side, livestock farming deals with biological individuals with individual development, behavior, demand, and so on. This aspect is absent in industrial production. Therefore, when transferring Industry 4.0 benefits to livestock farming, **Digital individualization** and **Demand orientation** take on different meanings, addressing the development and needs of individual animals or herds of animals.

The remaining five Industry 4.0 benefits are directly transferable and applicable to livestock farming: All pillars of **Sustainability** are relevant in livestock farming and may be stimulated and increased by Industry 4.0 concepts and technologies. Animal health and welfare must be regarded as an important part of the pillars of sustainability, if not supplemented as a fourth pillar in this context, as it receives lots of attention in public opinion and agricultural politics.

Livestock farming was always characterized by strong **Process orientation**. Despite the fact that on the farm, most of the process data are not gathered and most processes are not digitally interconnected, some process data are already collected and applied digitally, such as milking results from the AMS. Some suppliers of piglets, chicks, or feed already give digital information along with their delivery. Additionally, some slaughterhouses already transfer digital data. Still, in most stakeholder relationships with livestock farms, only a few data are exchanged, and only part of them by digital data transfer. More process data exchange will benefit not only the farm itself but also other stakeholders up to the consumer.

Repeated unmodified production cycles in livestock farming are an ideal precondition for **Automated knowledge and learning**. Sensor data from the production process may be used for problem recognition and correction. Local results data such as milking results from the AMS or weight development in fattening may be used for automated learning as well as external data, for example, weight, quality, and health data from slaughtered carcasses. Today, knowledge about the processes is often generated by the farmer. Upcoming comprehensive and intelligent Farm Management Information Systems (FMIS), like Lely Horizon or BFN Fusion, will include algorithms for automated knowledge and learning in the future.

Collaboration competence between farmers and other stakeholders not only needs digital process data exchange, as mentioned in the previous paragraphs. Another very important factor is the personal competence of the owners and working staff at farms and stakeholder companies. Industry 4.0 benefits may only be reached when people are well trained and motivated. Future FMIS will support increasing collaboration competence.

As more process data become available digitally, they may contribute to **Productivity optimization**. Data like the weight of fatteners, audiovisual animal observation, slurry content, and the lung and liver health of carcasses may help to control and optimize the processes. This is essential for increasing sustainability including animal health and welfare as expected by society.

5. Discussion

Livestock farming, in principle, offers good potential for Industry 4.0 technologies and concepts. Livestock farming almost completely takes place in buildings. Most machines have a fixed location and may be connected to a computer network via a cable. Mobile machines may be connected by local radio systems with limited extension such as Wifi.

Processes are highly standardized and repetitive. External factors such as weather induce much less impact in animal barns than in crop production.

Even with the focus of this paper on in-barn production at medium- and large-size farms, it should be noted that digital tools and Industry 4.0 potential also exist for very small farms and for pasture husbandry. Portable sensors, the GPS positioning of animals (e.g., Alptracker), and various software apps allow digital progress in these domains of the livestock economy as well.

The degree of automation and digitalization is already high in many large- and medium-size farms. Machines from different manufacturers often lack interconnectable standardized interfaces. Only part of the machines in livestock farming is digitally interconnected or connected to a central FMIS. This may be the biggest obstacle for further digitalization and the achievement of Industry 4.0 benefits. There is no standardized digital bus system in livestock farming. Technical solutions generally work well as long as the farm uses technology from only one manufacturer. Specialized big manufacturers for dairy farming or big 'fullliners' for poultry livestock farming technology are dominating their sectors. Only they offer fully integrated solutions including an FMIS. On the other side, there are some approaches available to interconnect multiple manufacturers, e.g. the software 365FarmNet, which was expanded to dairy farming. In the pig sector, there are many small manufacturers that are not highly interested in the technical collaboration of their systems. In this sector, the need for action is greatest.

Precision livestock farming (PLF) or smart livestock farming is an ongoing trend for 20 years [123,124]. PLF is principally based on the automatic online sensing of animal states and behavior by various sensors. In dairy farming, sensors may be attached to the cow because (a) the cow can bear sensors with heavy batteries, (b) the cow tolerates sensors attached to the body, and (c) the cow stays in the barn for a long time. In pig and broiler production, sensors are typically attached to the building infrastructure. Even in cases where the sensor is neither mounted directly at the animal's body nor equipped with an Internet address, these sensors approach the Industry 4.0 idea of the Internet of Things (IoT), connecting the animals (individuals or groups) to the farm's digital network. As described in Sections 4.2–4.4, the introduction of meaningful sensors, particularly for animal behavior, is still at a very early stage. Many research and development projects are dealing with such sensors. As related to sensing biological objects, the discrepancy between research claims and practical use seems bigger in livestock farming than in crop production. The application of pedometers for the heat detection of cows was pushed only from the moment when it was integrated and offered with automatic milking systems.

The current state of livestock farming is characterized by only little digital data exchange, not only between processes but also along the value chain. First approaches such as the HIT database for cows exist [73], but this database was first enforced by legal requirements, and thereafter, the sector recognized the potential of HIT besides its official use.

The lack of digital data exchange induces a lack of information transparency and widely the absence of a digital process view, while the production itself, e.g., in broiler production, has a clear process orientation. State-of-the-art FMISs often lack meaningful evaluation and interpretation algorithms, so that even stored process information is not evaluated and presented suitably for high-level decision support. The consequence of missing digital process representation and meaningful process evaluation and presentation is the disability of automatic learning and automatic optimization. Although the farmer receives detailed information about their products (milk, carcasses), they are hardly able to connect these output data to the process data for automatic learning and optimization.

The lack of powerful livestock sensors and a broad digital data exchange restricts animal welfare and labor easing. Such industry 4.0 technologies have the potential to boost animal welfare and health. The PLF approach enables the development of globally accepted health and welfare standards [125]. This may be contradictory to public opinion with its doubt that technology may promote animal welfare. A digital process control and process view may contribute to more sustainability in all its aspects, including resource efficiency, labor easing, and economic success.

As shown in the literature section above, the transfer of Industry 4.0 technologies and concepts to agriculture has been discussed since about 2018. Most of the published work addresses this topic by describing how several Industry 4.0 technologies may or already do improve livestock production, e.g., [14,125,126]. Braun et al. mentioned that Industry 4.0 may enable innovative business models in agriculture within the context of the value chain [12]. Bernhardt et al. introduced the idea of evaluating Industry 4.0 implementation options (benefits) for agricultural use cases. They found that livestock farming in current value chains has little need and options of flexibilization and demand orientation, while these benefits play an important role in industrial use cases [17].

The present study, with a deeper look into three livestock farming sectors, could confirm the lack of market demand for individual and changing product parameters and for the flexibility of livestock production within current value chains. On the other side, this study introduced the concept that in livestock farming, individualization and demand are not only driven by customers but also by the individual living animals or animal groups within the production system. Therefore, when discussing Industry 4.0 benefits in livestock production, the terms individualization and demand should be interpreted with both meanings.

Digital individualization promises further advantages: Processes and animals may be tracked and documented. This allows more information for the consumer, and in some cases, even extended business models.

Recently, Maffezzoli et al. published their work about Agriculture 4.0 benefits in this journal [127]. They derived benefits from the literature about smart agriculture effects and categorized them into four clusters: effectiveness, efficiency, environmental benefits, and social benefits. As such, it can be seen that when accessing Agriculture 4.0 from a smart agriculture viewpoint, sustainability, with its three pillars, is the central benefit of Agriculture 4.0. On the other hand, when looking from an Industry 4.0 point of view at livestock farming as in the study presented here, more relevant benefits become visible such as collaboration competence, automated learning, and animal health and welfare.

Another big challenge in this context is farmers' knowledge and open-mindedness for digital systems and an Industry 4.0 view of the processes. For the full use of digital systems on the farm, the farmer already needs a lot of knowledge that should be acquired in vocational education and in further training. Managing a farm at the Industry 4.0 level needs an understanding of the virtual representation of the processes, objects, and systems. Zambon et al. point out the importance of change in the mindset of farmers as a crucial prerequisite to activate an effective and sustainable production system that will last in the long term [13]. Goller et al. conclude that for this new kind of work, farmers require elaborated mental models that link traditional farming knowledge with knowledge about digital systems, including a strong understanding of the production processes underlying their farm [128].

6. Conclusions

Livestock farming differs from industrial production: Livestock production must cope with the market demand, but it must also cope with the needs of living animals. The animals on the farm are not "material", but they have their own ethical identity as living vertebrates and biological beings.

When discussing the potential benefits of Industry 4.0 in livestock farming, animal identity and welfare must be taken into account as part of the business use case. This directly affects the benefits of individualization and demand orientation. While in the industrial sector, these benefits mainly relate to customer demand, in livestock farming, individualization and demand orientation are also related to the needs, health, and welfare of the individual animal. Sustainability has very high relevance in livestock farming, first, due to the high importance of animal health and welfare, and second, due to the strong interrelation with the environment, primarily by greenhouse gas emissions and organic residues.

Many Industry 4.0 benefits are applicable and beneficial to livestock farming in a comparable manner as in industrial production: process orientation, automated learning, collaboration competence, and productivity optimization. Flexibility, however, has very little importance in livestock farming, since the high throughput production is very constant with very little requirement for flexibility.

Industry 4.0 technologies and concepts are applicable to livestock farming and can promote Industry 4.0 benefits as described in this article. Major challenges are (a) technical standards for interoperability between technology from different manufacturers, (b) meaningful sensors at affordable prices for animal behavior and for other parameters, (c) intelligent, integrated, and comprehensive FMISs that give the farmer valuable insight and decision support, and (d) farmers' knowledge and competence about Industry 4.0 benefits. The recent development of FMISs and data platforms already point towards Industry 4.0, but the other challenges still require huge effort and attention.

This study was worked out by a transdisciplinary team of experts in Industry 4.0 and experts in livestock farming. It should be noted that the study design did not strictly follow an acknowledged research method but was adapted to the procedure chosen to find the results. The procedure consisted of both unsystematic literature research and targeted discussion rounds to make use of expert knowledge in a structured manner.

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