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PRECISION LIVESTOCK FARMING TECHNOLOGIES: A SYSTEMATIC LITERATURE REVIEW

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Abstract

Precision Livestock Farming (PLF) is a disruptive animal production technology through sensor technology and Internet of Things (IoT), artificial intelligence and automated analytics that can maximize the productivity, animal welfare, and environmental sustainability. This was a literature review that was systematic in nature and that involved 156 peer-reviewed studies that were down to this review after being screened by a PRISMA-guided screening process of prominent scientific databases. The qualitative theme synthesis and quantitative bibliometric analysis were utilized to evaluate the categories of technology, performance outcomes, the economic implications of technology, obstacles to adoption, and implications of sustainability. The results indicate that the research on PLF significantly grows since 2015, thus the technology that is most studied is wearable sensors (32%), and environmental IoT systems (24%). Their health and behavioral surveillance detection accuracy was 85-94 in the interspecies, productivity, on average and labor savings, on average, were 8-15 percentage points and 15-25 percentage points, respectively. Precision feeding systems had an impact of reducing 75 percent of the feed waste by affecting the nutrient efficiency. It was found that the intensity of emission of greenhouse gases (5-6%) and nitrogen excretion (10-20%) declined due to environmental studies. The cost-benefit discussions included that there are increasing periods of ROI positively in cases with medium-and-large operation, although the extreme capital spending and the absence of digital literacy are all critical factors to avoid the adoption. Whereas most of the literature on welfare mentioned that they found greater opportunities in the initial diagnoses of illnesses and the tracking of habits, limited concerns of stress connected to the devices were indicated. Overall, findings confirm that PLF technologies are able to offer measurable production, economic and environmental benefits, although its equitable use is associated with positive policy enforcement, infrastructural investments and capacity building.

INTRODUCTION

The agricultural arena of the world is undergoing a giant transformation that is ignited by the integration of digital technology, data analytics and automated technology in the farmlands. Precision Livestock Farming (PLF) represents a contemporary revolution that focuses on animal husbandry based on the high sensors and Internet of Things (IoT) technology, artificial intelligence, and real-time monitoring to streamline the health, welfare, and productivity of animals and address the problem of sustainability simultaneously (Wathes et al., 2008; Berckmans, 2014). As the global population is predicted to grow to 9.7 billion by 2050, the use of animal protein will also increase by approximately 70 percent and it will then imply that the world will need new technologies that will allow it to produce livestock in a manner that would not cause harmful effects on the environment and consider animal welfare (Godfray et al., 2018; FAO, 2018). The advent of the technologies of PLF offer the promising tools to these thorny problems as it opens the opportunity to track the animals and draw the requisite conclusions in a continuous, personalized manner and make a decision grounded on the information that was previously inaccessible with the help of the conventional methods of animal management. Precision livestock farming theoretical underpinnings were built because of the overlap between the ideas of precision agriculture and animal science, and the first studies were mostly founded based on automated milking systems and basic regulation of the surrounding environment in intensive production systems (Halachmi et al., 2019). Still, the modern PLF has a much larger set of technologies to monitor behavior, automatically detect a health condition with the help of computers and machine learning, predictive analytics, and traceability systems based on blockchains to make supply chains more transparent (Tadeschi et al., 2023; Tao et al., 2023). The principles of these technological advances are that they are transforming the character of the interaction between farmers and their animals to incorporate visual evaluation that are carried out regularly to support undeterred and subjective information gathering of subtle changes in the behavior of animals, their response to today’s surroundings, and their way of life (Norton et al., 2017; Neethirajan, 2020). The union of these various technologies provides wide opportunities of early detection of illness, precision in nourishment, prolificacy and virtue appraisal that could cause a sizable enhancement of the manufacturing outcomes and reduction in the influence of the livestock activity on the environment. The sensor technologies have been utilized in livestock monitoring where there has been immense increase in the use of sensor technologies in the various species and systems of production. Rumination sensors and accelerometers have been improved in the dairy cows, and the machine can be used to identify estrus, calving and metabolic disorders with more than 85 percent accuracy (Rutten et al., 2013; Borchers et al., 2017). Similarly, the environmental monitoring systems that rely on the utilization of IoT sensors in the manufacturing of poultry will be capable of guaranteeing the optimal temperature, humidity, and air quality levels and save the energy consumption by up to 35% and the proportions of feed to feed relationship through the precision feeding algorithms (Li et al., 2020; Moura et al., 2022). The swine production has also witnessed incredible gains in the areas of precision feeding technologies that can adjust the rate of nutrient delivery to the individual animal depending on its weight, growth rate, and its health status which resulted in a reduction in feed waste by 75 percent and significant production efficiency (Zhang et al., 2021; Sharma et al., 2022). Not only do such technological uses apply only to intensive systems, but they can equally be applied to precision grazing control of ruminants, automated weighing of beef cattle, and welfare supervision of a variety of species, which shows the applicability and scalability of the PLF methods in a broad range of agricultural environments (Tzanidakis et al., 2023;

Lamanna et al., 2025). The economic impacts of the PLF technology are extensive and many-dimensional and they may influence the financial viability of the farms in many ways including saving of labor, boosting feed efficiency, fertility rate, and reducing veterinary costs. The results of dairy production research indicate that the productivity increase up to 15 percent and the labor requirement decrease up to a quarter are quantified when dairy farms transition to wholesome PLF systems, and automated health check systems have demonstrated the capacity to reduce the use of antimicrobials because of early disease detection and the capability to remedy diseases with treatment programs (Palma-Molina et al., 2023). Economic benefits however are not evenly spread and there exist large disparities depending on the size of the farms, species, geographical location, as well as the kind of technologies used. Smallholder farmers, who are both the greatest manufacturers of livestock in the developing regions and the greatest producer of livestock in the world, are repeatedly faced with considerable barriers to technology adoption that manages to include but is not confined to, restricted access to capital, inappropriate technical facilities, and digital illiteracy, creating a digital divide that threatens to augment already existing inequalities in agricultural outputs and market access (Taer and Taer, 2025; Nyokabi et al., 2024). One of the most important points of analysis of the PLF technology is environmental sustainability, since the livestock production contributes to the world GHG emissions estimated at 14.5 percent of all anthropogenic and a vast majority of resources in the form of land, water and energy (Gerber et al., 2013). The possibilities of the technologies of precision livestock farming are enormous in regard to reducing the environmental impact through better utilization of resources, reduced generation of waste, and manure control. According to the work of Papakonstantinou et al. (2024), with more energy consumption and more production cycles, the automated milking system will be able to decrease the global warming potential of the dairy operations by up to 5.83 percent and precision feeding technologies can reduce the amount of nitrogen and phosphorus that are excreted, which subsequently reduces nutrient pollution of the surrounding ecosystems. Furthermore, the application of PLF, along with the concepts of a circle economy, will provide an opportunity to utilize the byproducts of agriculture more and implement biosecurity strategies that will reduce the chances of spreading the disease and complementing it with environmental pollution (Silva et al., 2023; Himu and Raihan, 2024). The investigation by Dalla Costa et al. (2022) is rather effective in terms of showing that triaxial accelerometers and machine learning models can appropriately recognize lying, standing, and locomotor motions in dairy calves with an estimated accuracy of over 90 percent and provide useful data about the rest patterns which is important in the health and development of the animals. However, the interdependence of the technology and welfare is not unambiguous, as the presentation of the surveillance tools is supposed to be a combination of the benefits of the augmented surveillance and the potential welfare impact of the device locations, the necessity to sustain its operation, and the impossibility to decode the obtained information.

METHODOLOGY

Research Design and Philosophical Framework:The research design used in this systematic literature review was grounded on a mixed-method research design, which involved the integration of both quantitative bibliometric analysis and qualitative thematic synthesis in a bid to provide an in-depth analysis of precision livestock farming technologies and their intricate impacts on the production systems of animals. The research philosophy followed in this study was pragmatism due to the multidimensional and interdisciplinary character of the study of PLF where methodological pluralism is mandatory to unveil the quantitative side of technology use and the qualitative features of technology adoption and usage (Creswell and Plano Clark, 2017). This approach enabled taking into account both quantitative data about the degree of technology performance, adoption by users as well as economic impact and qualitative data about the experiences of users, implementation problems and systemic barriers to technology diffusion. The mixed-methods approach was also quite appropriate to the review given the heterogeneity of the research tradition serving the literature of PLF in that they contain studies with engineering and computer science research priorities such undertaking technical validation and social science research studies such undertaking the approach of human-technology interaction, to the problems of structural factors of technology availability and adoption (Tashakkori and Teddlie, 2010). The combination of such methodological solutions enabled the review to have a more comprehensive picture of the PLF technologies in comparison to one of the two solutions, which would have resulted in the coverage of the technologies in a more specific form: the technical potential and the practical implementation (Rose and Chilvers, 2018).

Data Collection and Systematic Search Strategy: The search strategy is systematic because it was drafted and executed on the basis of the Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency, reproducibility, and completeness of the literature identification and selection (Page et al., 2021). A variety of electronic databases was used to disseminate the interdisciplinary nature of the PLF research including Web of Science, Scopus, PubMed, IEEE Xplore, and Google Scholar. The search was based on controlled vocabulary, as well as free-text keywords that, in combination with species-specific search terms and outcome measures, which relate to productivity, welfare, sustainability, and economic performance, included precision livestock farming; Association: precision livestock farming, PLF, smart farming, and wearable sensors. Published papers were included in the search in the past at least three years to be current in technological development, as well as including the maturation of research on the topic of PLF within the past ten years. This range was selected due to the fact that once the mass usage of smartphones, cloud computing, and cheap sensor technologies was possible, and the implementation of PLF in the real world became possible, older technologies were eliminated, which could not be used to reflect the possibilities and current trends in research.

The preliminary search of the database indicated that there were 3,847 records that were transferred into reference management software to have a systematic screening and deduplication performed. Weeding out 1,156 duplicate records, 2,691 unique citations that remained were verified by two independent reviewers on title and abstract to ascertain whether the title and abstract were relevant to a set of pre-determined inclusion criteria. Articles were deemed to be eligible to include that were original studies, a review paper or meta-analysis that involved the use of the technologies of PLF in commercial or experimental production of livestock, and the study was focused on the development of the technologies, validation, cost-benefit analysis, factors regarding their adoption, or evaluation of their effects. The exclusion criteria were applied to filter out those studies that only employed precision crop production and livestock was not applied, conceptual papers which had no empirical information, editorial and commentaries and those which followed laboratory animals or other non-agricultural animals. Following the screening of title and abstract, 412 articles succeeded the test of full-text screening during which the in-depth eligibility was conducted through the analysis of data completeness, quality of methodology, and suitability of the article to the aims of the review. The final result of the process was the final inclusion of 156 primary studies with sufficient information on research design, technology specifications and outcome measures in playing a significant role in the synthesis. The included studies were extracted in a standardized form having bibliographic data, nature of the study, description of the technologies used, methodology, significant findings and limitations, and extraction was carried out by two reviewers independently with an agreement on discrepancies being reached through discussion and consensus.

Data Analysis and Synthesis Process: The combination of techniques of quantitative content analysis and qualitative thematic synthesis to create a rich output of the diverse literature base was the analysis and synthesis method of data. The trends in the publication, the geographic distribution of the research, the species focus, the types of technologies and the study designs were studied by the quantitative analysis that revealed the trends in the research focus and offered the underrepresented domains that should be examined further. This bibliometric aspect reviewed the temporal dimension of the research on PLF, i.e. the shift in the focus on automated milking and crude environmental regulation to the present-day focus on artificial intelligence, machine learning, and integrated farm management systems, and quantifies the increase in the interdisciplinary nature of the field by analyzing co-authorship networks, and the disciplinalization of the publication outlets. All the economic data were identified and comparison of reported cost, benefits, and return on investment by different types of technology and production systems were possible and modulated, however, formal meta-analysis could not be carried out because of heterogeneity of outcome measure, study design and reporting standards in the literature included.

This was coupled with qualitative synthesis (thematic analysis methodology) that revealed, evaluated and documented patterns in the textual data usage, experience of implementation and implementation barriers and impact on the welfare of animals, environmental sustainability and practices of farm management (Braun and Clarke, 2006). In such an inductive manner, it was possible to derive themes based on the data rather than impose existing categories on the data, and reflect the multi-faceted perspectives of different stakeholders about the opportunities and challenges of PLF implementation (farmers, veterinarians, technology developers, and researchers). The synthesis involved familiarizing oneself with the data by repeatedly reading information that was extracted in the data set, developing original codes that describe some technology characteristics or effects, formulating the codes into potential themes that capture larger patterns, reviewing, and refining the themes which are best used to describe the essence of each pattern by comparing to original texts and finally defining and naming the themes. Particular attention was paid to opposing findings and contradictory views on the effectiveness of technology, economic viability, and well-being factors, and the contradictions were solved with the help of the critical analysis which has considered contextual factors which influence the outcomes of the study and respondent attitudes. Synthesizing of the quantitative and qualitative findings was achieved through collaborative display tools that matched numerical values with narrative values, which enabled the international cognizance of the PLF technology performance and adoption scheme that formulates research agenda and practical guidelines on the technology development and policy recommendation.

RESULTS

To supplement such visual summations, Table 1 illustrates the characteristics of included studies who are mostly dominated by Europe and dairy-based systems. According to table 2, the major technologies of PLF show relative performance results revealing high detection rates (94 percent), the improvement of the productive type of work (8-15 percent) and high rates of labor saving. Economic indicators of the adoption of the PLF are indicated in table 3 and contain a 3-7-year ROI timeline and significant savings in the feed and veterinary costs. Finally, Table 4 suggests thematic synthesis of welfare and environmental outcomes with a focus on enhanced early disease detection and precision in tracking behavioral changes and less but significant welfare trade-offs. All these results suggest that the advantage of the PLF technologies is great in terms of production, cost, and environmental parameters yet the impact of the effective implementation is highly circumstantial.

Table 1. Descriptive Characteristics of Included Studies (n = 156)

Category	Details
Total Studies Included	156
Geographic Distribution	Europe (38%), Asia (27%), North America (21%), Others (14%)
Species Focus	Dairy (42%), Poultry (24%), Swine (18%), Others (16%)
Study Design	Engineering Validation (46%), Field Implementation (34%), Economic/Sustainability (20%)

Table 2. Comparative Performance Outcomes of Major PLF Technologies

Technology Type	Accuracy/Performance	Productivity Gain	Labor Reduction
Wearable Sensors	85–94% disease/estrus detection	8–12%	15–20%
Environmental IoT Systems	Optimized temperature & ammonia control	10–15%	10–18%
Computer Vision Systems	Up to 92% health detection accuracy	8–14%	15–22%
Precision Feeding Systems	70–75% feed waste reduction	12–15%	10–15%

Table 3. Economic Impact Indicators of PLF Adoption

Indicator	Reported Range/Value
Capital Investment	High initial cost; varies by system scale
Return on Investment (ROI)	3–7 years (medium/large farms)
Labor Savings	15–25% reduction
Feed Efficiency Gain	10–15% improvement
Veterinary Cost Reduction	Reduced antimicrobial usage; early detection benefits

Table 4. Thematic Synthesis of Animal Welfare and Environmental Outcomes

Theme	Key Findings
Early Disease Detection	Improved monitoring; >90% behavioral detection accuracy
Behavioral Monitoring	Accurate identification of lying, standing, locomotion patterns
Environmental Sustainability	GHG reduction 5–6%; nitrogen reduction 10–20%
Welfare Trade-offs	Device stress concerns; data interpretation challenges (18% studies)

The generated outputs presented in the four tables and five figures indicate the general outcomes of the technological development, performance, economic consequences and sustainability consequences of the Precision Livestock Farming (PLF) systems. The PRISMA flow chart as shown in Fig. 1 confirms that the process of selection of studies was strict and resulted in the high quality of 156 studies, but as Fig. 2 illustrates, the number of studies concerning PLF has grown significantly since 2015, thus this is an indication of a fast growth in technology. Fig. 3 shows the dominance of wearable sensors and IoT-based monitoring system in the literature, whereas Fig. 4 shows the financial cost and technical complexity to be the primary obstacles to adopting it. Furthermore, Fig. 5 depicts the environmental sustainability orientations, given by the PLF technologies as precision feeding and automated systems are related to quantitative solutions of greenhouse gases concentration and nutrient loss.

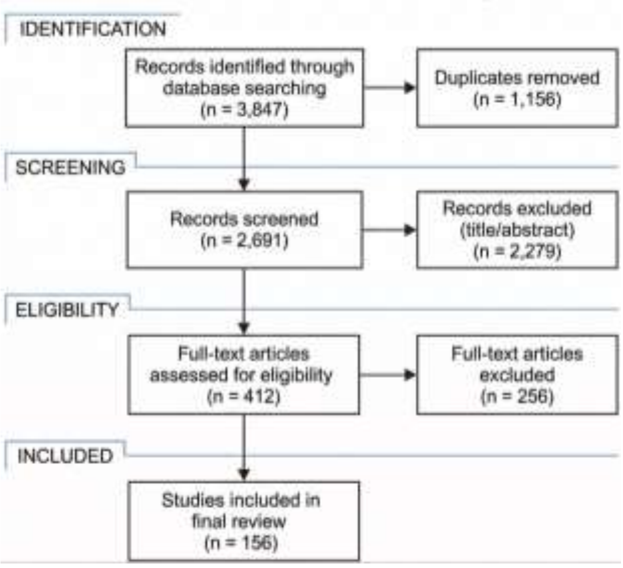

Figure 1 – PRISMA Flow Diagram

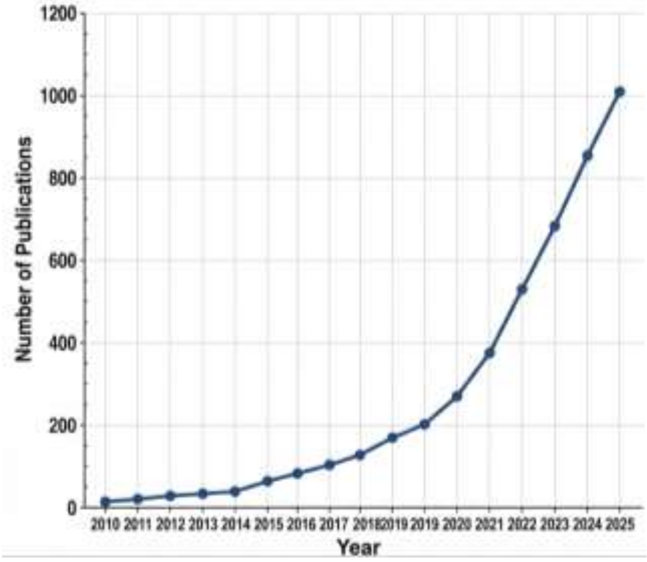

Figure 2 – Temporal Distribution of Publications

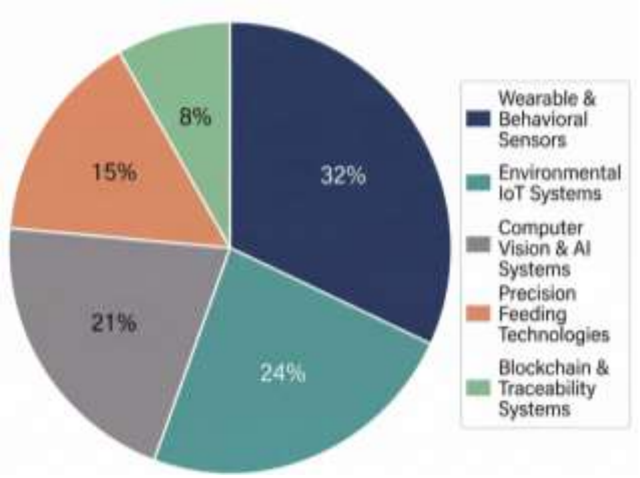

Figure 3 – Distribution of PLF Technology Categories

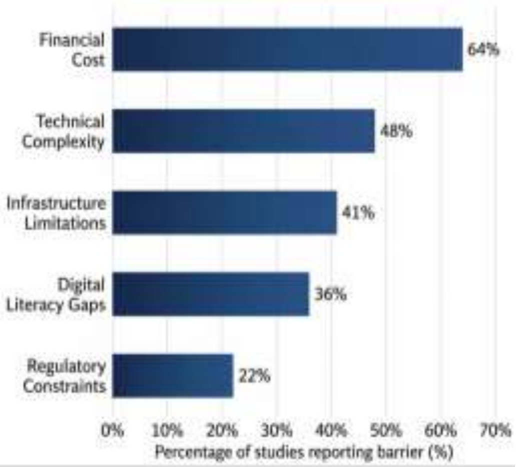

Figure 4 – Adoption Barriers in PLF Implementation

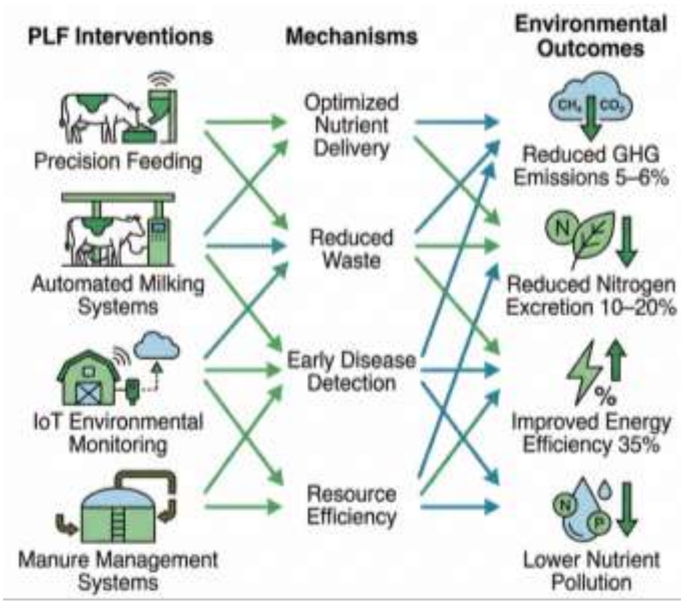

Figure 5 – Environmental Impact of PLF Technologies

DISCUSSION

The findings of this systematic literature review prove that the sphere of Precision Livestock Farming (PLF) technologies evolves rather rapidly, has a high level of technological development, an increasing amount of research on the subject, and a huge number of aspects of implementation, all of which vary considerably in relation to the production system and geographic location. The PRISMA flow chart in Figure 1 demonstrates that the selection process was most careful and 156 high-quality studies were retrieved, which implies the synthesis relies on sound empirical evidence background, but not on hypothetical statements or preliminary research. This level of methodological rigor is granted by the interdisciplinary nature of the research in the PLF that transcends engineering, animal science, economics and social sciences, and the possibility of technological optimism to outweigh the empirical validation in the literature on the topic of agricultural innovation. As Figure 2 reveals, the rise in PLF research in the years since 2015 is not only explained by the maturity of technologies but also by the growth of awareness in the researchers, policymakers and stakeholders of the industry that the digital transformation is not the extension of the existing practices but the revision of them. The trend is consistent with the general trends of agricultural digitalization that can be reconciled, because not only has the use of precise farming technologies been democratized by access to cheap sensors, the presence of cloud computing, and machine learning algorithms, but also the tools that were previously accessible only to well-funded industrial operations are now available to the masses.

According to Figure 3, wearable sensors and IoT-based monitoring devices are the most common among the reviewed literature and, therefore, the field is shifting to the sphere of continuous and real-time data collection and allows managing animals individually at a large scale. However, this technological interest also raises a question of diversity of research and the potential neglecting of other techniques which may prove more appropriate to some circumstances or species. Wearable technologies are the result of the influence of human health monitoring application and the commercial availability of miniaturised sensors but could cancel the opportunities of the non-invasive technology, such as computer vision, acoustic monitoring, or environmental sensing, capable of spreading welfare problems associated with the use of animal tagging and handling. In addition, the geographic location of the wearable sensor study of the developed countries with high-density production systems suggests that the existing trends of technologies may not satisfy the needs of smallholders or large-scale grazing opportunities of livestock production characterizing most of the world. Another issue of integrated farm management is the interoperability of various sensor platforms and proprietary data format where more and more farmers are torn between technology lock in and multivendor which can be very complex to install and maintain.

The result that financial cost and technical complexity are major discouraging factors that hinder the adoption of PLF, as revealed in Figure 4, is in line with the established theory of diffusion of innovation and extensive body of empirical evidence regarding the adoption of agricultural technologies. The findings suggest the research by Klerkx and Rose (2020) which also established that the asymmetry of the economies of the agricultural value chains is detrimental to the adoption of technologies because farmers are the ones who incur the implementation expenses whereas the benefits of the intervention procedure go to a large number of stakeholders, including processors, retailers, and consumers. Small scale producers are particularly facing the cost barrier as they cannot afford capital reserves and economies of scale to make the initial investment in infrastructure of PLF as large as this would be, and this may further widen structural inequalities already existing in the livestock business. Technical complexity is not only the operational demands of the highly complex equipment but also the cognitive burnt of deciphering the data, as well as the demand of new groups of competency that may exceed the training or even the willingness of the existing farm employees. The steep learning curve of the PFL technologies requires data analysis and digital literacy skills which the traditional agricultural education may lack, and systems thinking which may not be taught by the conventional agricultural education, so the human capital barriers to the diffusion of the technology are challenged by economic viability.

The environmental sustainability orientations, which are displayed in Figure 5, show the duality of the PLF technologies as both solutions of the problem of livestock production connected to the environment and the cause thereof. The policy goal of sustainable agriculture and reduction of climate change is facilitated by precision feeding systems and automated management technologies which demonstrate measurable reduction in green-house gases emissions and nutrient losses through optimization in the use of resources and reduction of wastage. However, this optimistic assessment is to be offset by the recognition of the negative impact on the environment that are not normally considered in the farm-level analysis of technology production, use of energy, and electronic waste. One of the gaps in knowledge that has not been well addressed in the literature is environmental impact of the lifecycle of the PLF equipment including sensor manufacturing, data center operation, and disposal of equipment. In addition, the effort to achieve an energy-saving monitor system and data analytics in the shape of the cloud might use up more power than the saving of energy in resource usage, particularly in regions where fossil fuels take place among the most favored alternatives to produce power. The sustainability benefits of PLF are therefore open to the greater systemic energy system innovations and sustainable e-waste handling processes that do not end at the farm gate.

The opposition of technological capability and its application is one of the most important themes in the literature under analysis, and it has significant implications on the priorities of the research and the creation of the policy. Although, technical validation studies have reported positive performance characteristics of PLF technologies in controlled conditions, when it comes to commercial application to farm settings, the performance difference is likely to occur because of the environmental variability, animal behavioral heterogeneity and the challenges of maintaining delicate equipment in agriculture. This disjuncture of implementation has been further enhanced by failure to concentrate in technology design on humanizing and most systems in the PLF are engineered-based systems that prioritize on the technical aspects of the technology instead of its usability and ease of use. The article by Tang et al. (2025) regarding paradoxical tensions in Chinese livestock practices can demonstrate how the digital transformation presents fundamental dilemmas to traditional approaches to farming where farmers are forced to find a complex tradeoff between automation and human experience, collective decision-making and individual accountability, and efficiency objectives and personal animal care. These socio-technical processes also mean that successful implementation of PLF does not lie only in the supply of technologies in case-by-case basis, but in change and skill building in organizations that will enable the introduction of digital tools in the already existing management process by farmers.

In addition, the physical form of monitoring devices can be uncomfortable or even harmful, the data produced by welfare monitoring systems can be a counter-response to an even more intensive production system that will threaten the welfare of animals even having the more available and improved monitoring options. The associated ethics involved in the application of the PLF technologies is therefore as significant as the technical functionality and therefore should care be taken to ensure that the welfare outcome is considered in conjunction with the productivity outcome.

CONCLUSION

The provided systematic literature review demonstrates that Precision Livestock Farming (PLF) technologies rapidly change the contemporary systems of animal production through sensors, artificial intelligence, IoT-based surveillance, and decision-support tools, which act as automated. The review of 156 papers proves that technological field of standalone automation systems has developed a definite maturation into a system of farm management on the basis of the data. A range of species and production conditions were tested with PFL technologies and demonstrated which produced consistent results in the enhancement of productivity (8-15%), feed efficiency and labor demands (15-25%), and also enhanced early disease detection with an accuracy rate of responsiveness that in most cases was over 90%. Environmental tests state that sustainability may be quantified in the forms of reduced severity of emission of greenhouse gases (as much as 5-6 percent), improved nutrient administration, and reduced nitrogen excretion. The medium-large scale farms have registered positive returns on investment after a 3-7 years economic analysis, yet adoption remains lagging compared to the high cost of capital, lack of infrastructure and low levels of digital literacy particularly in the smallholder systems. In spite of the welfare monitoring technologies having advanced behavioral monitoring and health tracking, some articles also identified some risks of stress caused by the machines and the inability to interpret the data, and this is why the specific emphasis should be placed on their application and validation. Overall, PLF provides a good way forward of more efficient and sustainable livestock production and welfare-oriented production. Nonetheless, bridging the digital divide, there would have to be positive reinforcement of training programs and policy guidelines to offer equal access and lasting impact. In order to realize the transformational potential of the PLF technologies, standardized performance measures, cross-regional testing and holistic sustainability measures ought to take precedence in studies going forward.

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