MARKET ANALYSIS

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Facilitating PLF Technology Adoption in the Pig and Poultry Industries

The importance of Precision Livestock Farming (PLF) technologies in agricultural practices is widely recognised, yet the actual adoption rate remains low. To address this issue, research with several interconnected sub-studies was initiated across seven countries to encourage PLF technology utilisation. Initially, 15 farms received PLF tools to showcase their benefits. Despite successful deployment, challenges such as animal behaviour, sensor positioning, and internet connectivity affected operational efficiency. Concurrently, surveys were conducted to assess livestock producers' attitudes and identify adoption barriers. Subsequently, a sophisticated cloud-based ICT tool was developed to integrate research outcomes. The findings have highlighted concerns regarding the cost, complexity, maintenance, and perceived benefits of PLF technologies, exacerbated by internet connectivity issues in rural areas. Machine learning analysis identified the technological readiness levels of farmers, providing information for the development of the new PLF Compass tool. This integrated application facilitates technology adoption by offering personalised recommendations and benefit assessments.

Keywords: PLF/smart technologies, ICT tools, adoption, implementation, technology barriers

JEL classification: Q11

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Introduction

Increased adoption of Information and Communication Technology (ICT) based (or Smart) tools, such as Precision Livestock Farming (PLF) technologies in livestock production holds critical significance for countries aspiring to attain economic competitiveness, social inclusivity, and environmental sustainability (Banhazi *et al*., 2022c). Properly implemented Smart PLF technologies in diverse animal production systems offer livestock producers enhanced effectiveness and efficiency in monitoring and controlling environmental conditions, as well as optimising the health, welfare, and production efficiency of animals (Olejnik *et al*., 2022b; Olejnik *et al*., 2022a; Hoxhallari *et al*., 2022; Mallinger *et al*., 2022). However, the current adoption rate of PLF technologies in animal production is still much lower than expected primarily due to implementation complexities and difficulties encountered during PLF installations on farms (Banhazi *et al*., 2022c). These difficulties are often associated with unreliably internet connections in most rural areas within various countries (Banhazi *et al*., 2022d; Nääs *et al*., 2022). The additional challenges associated with PLF tools include the lack of readily available training (Cosby *et al*., 2022) and some of the unexplored ethical aspects of using PLF tools (Guzhva and Siegford, 2022).

However, it has also been proven that some of the PLF technologies could significantly improve the environmental and economic viability of animal production (Niemi *et al*., 2010; Kamphuis *et al*., 2015; Fournel *et al*., 2017; Black and Banhazi, 2022; Black and Banhazi, 2013). Despite all this, livestock producers are not necessarily open to using PLF technologies due to a lack of in-depth knowledge about the proper implementation and usage of these smart tools. To increase the adoption rate of PLF/smart technologies, the socio-economic and cultural barriers preventing the wider adoption of PLF/smart technologies have to be better understood and ultimately eliminated. Thus, to identify/remove social barriers for technology adoption and to achieve a wider use of PLF/smart technologies on farms, research was implemented in seven (7) different countries, including Austria, Denmark, Estonia, Hungary, Israel, Poland, and Sweden (with altogether 9 different academic and commercial partners participating). In turn, it was expected that the improved smart technology adoption rate would foster green growth, further the process of digitisation in the EU and increase farmers' openness towards PLF technologies.

Materials and Methods

The objectives of the research were achieved by implementing seven self-contained but interlinked sub-studies. First, 15 farms in five countries were selected and supplied with PLF tools. To quantify the benefits of these tools under commercial on-farm conditions, an Automated Data Analysis and Management System (ADAMS) database was developed. The ADAMS database aimed to efficiently receive, store, manage, analyse, and automatically report data collected by various hardware tools, such as the Enviro-Detect^{TM} and Weight-Detect^{TM} sensor systems (PLF Agritech, Toowoomba, QLD, Australia) installed in study buildings.

Concurrently, well designed and methodically implemented quantitative and qualitative surveys were conducted to (1) understand the attitudes of livestock producers towards PLF tools and (2) identify key barriers limiting the adoption of smart/PLF technologies. 'Mixed social science methods' were used to explore beliefs and management behaviours related to human-animal (Hostiou *et al*., 2017) and human-machine interactions (Chen *et al*., 2002). Specifically, quantitative questionnaire templates were developed for online survey on the current use of PLF tools within a representative sample of respondents managing and/or being employed on commercial poultry and pig farms. The standardised online questionnaires were filled in by 121 pig farmers and 145 poultry farmers (Tikász *et al*., 2023b). In-depth interviews and focus group discussions (FGDs) were conducted to obtain qualitative insights. FGDs involved 83 participants from the pig and poultry value chain, including policy makers, livestock producers, technology providers, and ICT developers. Four main themes were covered by the focus groups: (1) implications regarding the application of ICTs; (2) general description of ICT-users; (3) main barriers (lock-ins) of the adoption of ICTs; and (4) incentives that might motivate the spread of ICTs (Tikász *et al*., 2023a).

Later, a complex software development process was undertaken, to create an integrated and cloud-based ICT tool that captured the key outcomes of this research (Mallinger *et al*., 2023). This work had essentially three major components. First, a k-means clustering approach was used to identify distinct clusters of users (livestock producers who are considering the implementation of some smart/PLF technologies) and their technological readiness based on the data from the quantitative survey. The clusters have been validated through a mixed-method approach, incorporating internal metrics, a principal component analysis, and a focus group evaluation. Based on this, a Decision Tree classifier was developed to associate the farm (survey) characteristics with the cluster affiliation and provide an executable model that can be incorporated in the LivestockSense PLF Compass: User Classifier ICT tool. As a second step, (based on the cluster and classification results) sets of practical recommendations have been developed by the research team to assist livestock producers increase their chances for successful technology implementation on farms. Thus, the LivestockSense PLF Compass: Advice Generator application users will have the opportunity to enter their answers into the on-line tool, to get tailored advice (based on their level of technological readiness identified by the LivestockSense PLF Compass: User Classifier) on how to reduce or even eliminate the identified barriers to PLF tool adoption. As a final step, a LivestockSense PLF Compass: Benefit Calculator have been created that estimates the extra financial benefits associated (and expected) from the implementation of smart environmental improvement technologies specifically.

Results and Discussion

Sub-study 1: Detailed review undertaken about past EU studies and projects

The first phase involved a comprehensive assessment of ICT-related technological solutions in the pig and poultry sectors. Drawing on insights from completed EU studies and research projects, the review identified gaps and deficiencies in Precision Livestock Farming (PLF) technologies. The implementation of PLF is driven by the potential for enhanced livestock management. However, farmers are understandably cautious and require proven benefits, affordable prices, and reliable maintenance. There are several concerns regarding the adoption of smart technology, including high costs, operational complexity, slow maintenance, and insufficient evidence of technology benefits. In addition, issues of data ownership, access, and the scarcity of qualified service providers are also a cause for concern. Furthermore, internet connectivity problems, particularly in rural areas, pose a significant hurdle to smart technology adoption, reflecting the 'digital divide' between urban and rural regions in many countries (Kopler *et al.,* 2023).

Sub-study 2: Quantitative and qualitative surveys implemented

The quantitative questionnaire results obtained enabled the research team to (1) ultimately develop a predictive 'technology readiness' model and (2) develop a good understanding of the status of ICT tool adoption today in altogether 6 EU countries plus Israel. Based on the responses it was found that the existing level of automation on the farms, the average age of the livestock buildings and associated production technologies, the availability of internet connectivity (i.e. networks within the livestock building which are able to reliably connect to the internet) together determine the "readiness levels" of livestock producers to adopt smart/PLF technologies (Table 1).

Depending on whether they were current users or non-users of smart technologies, respondents' perceptions differed significantly regarding the ease of access to these technologies on the market, their operational reliability, costs of maintenance and the ease of access to technical assistance for these

Table 1: Difference between users of PLF technologies and non-users.

Users	Non users
Highly, moderately automated farms	Medium or low automated farms
The average age of their buildings and production technology is less than 20 years, or even 10 years. Buildings and equipment older than 20 years are almost uncommon.	The age of their buildings and housing technology tends to be between 10 and 20 years old, or mixed, with buildings and equipment older than 20 years also occurring.
Internet connection opportunity by 96% of the farms.	Internet connection opportunity by 86% of the farms.
Network within the livestock buildings which can connect to the internet by 77% of the farms	Network within the livestock buildings which can connect to the internet by only 44% of the farms

Source: Own composition

Table 2: Users of PLF technologies agree in six countries about the matters listed in this table.

Denomination	Users	Non-users
Smart technologies provide information in a real-time manner	89%	67%
Smart technologies enable to increase the effectiveness of production	88%	56%
Smart technologies provide reliable information.	81%	56%
Smart technologies prove/improve transparency within production.	81%	50%
It is easy to access smart technologies on the market.	**69%**	**19%**
Smart technologies operate in a reliable manner.	**61%**	**22%**
Smart technologies are easy to operate.	59%	31%
It is easy to get information on smart technologies and distributors.	56%	25%
Smart technologies can be maintained at a reasonable cost.	**47%**	**8%**
It is easy to get technical assistance to smart technologies.	**47%**	**8%**
Proper education is available for using smart technologies.	44%	11%
Smart technologies can be purchased at an affordable price.	31%	3%

Source: Own composition

Precision livestock farming readiness

Based on your answers, you are one of those users who know the real potential of PLF technologies and are fully ready to use PLF technologies or are already widely using them.

Buildings and equipment in your farm are likely to be suitable to accommodate smart technologies.

Your farm and livestock buildings are rather well-equipped with internet access, which is a very important condition for the deployment of smart technologies.

You have confidence in smart technologies and believe that they can be a great help in allocating work at your farm as well as enable to increase the effectivenes of production. You consider ICTs as an important decision support tool. Therefore, your concerns about data protection, data management of these new technologies are moderate. You can afford the cost of purchasing and maintaining smart devices and find ways to overcome the difficulties of operating them and connect them with your other tools. You have no problems acquiring and keeping up to date with knowledge about smart devices, and you know what sources of information to rely on. You also have sufficient experience in the maintanance of smart devices.

As a potential advanced PLF user, the main challenge for you is to take full advantage of economic and environmental potential of PLF technologies, keep up your achievements and improve your operation.

Figure 1: LivestockSense PLF Compass: User Classifier.

Note: After answering 17 questions, the users are classified into three categories, such as Advanced, Progressive, and Starter users.

Source: Own composition

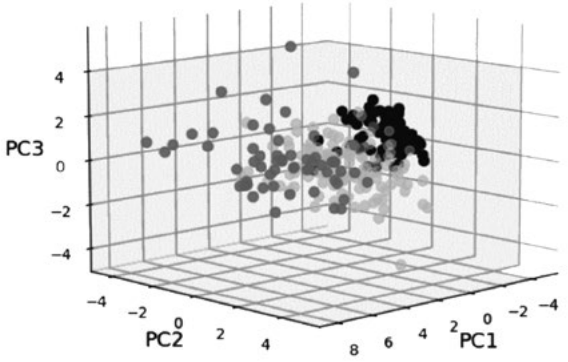


Figure 2: Principal Component Analysis (PCA) using k-means labelling with k=3 clusters.

Note: The visualisation of the dataset onto the three-dimensional space indicates a clear separation between the groups over the totality of answers. The three shades of gray representing the three separate clusters.

Source: Own composition

technologies (Table 2). By large, current users held significantly more optimistic/positive views on these matters when compared to non-users (Tikász *et al.*, 2023b).

Sub-study 3: Machine learning used to identify clusters of technology users

The machine learning analysis was undertaken to predict the readiness levels of farmers for adopting PLF technologies and the outcome of this analysis/modelling was incorporated in the LivestockSense PLF Compass: User Classifier application (https://plfag.info/question/1) (Figure 1). This study used machine learning, particularly k-means clustering, to identify distinct clusters of users and their technological readiness to adopt various PLF technologies based on their responses to a previously mentioned quantitative questionnaire. The analysis eventually revealed three distinct clusters (Figure 2) representing different levels of technological readiness among farmers considering the adoption of various PLF technologies (Mallinger *et al.*, 2023).

Utilising these clusters, a Decision Tree model was employed to predict the class affiliation, achieving an accuracy level above 80% (Mallinger *et al.*, 2023). This enabled the research team to generate sets of recommendations suitable for the three distinct user categories.

Sub-study 4: PLF Compass application developed

The research team utilised these findings to create recommendations for removing barriers for technology implementations. The recommendations have been integrated into the LivestockSense PLF Compass: Advice Generator section of the application https://plfag.info/index (Figure 3). Producers use the PLF Compass to evaluate their technology readiness levels and receive specific recommendations for increasing the likelihood of successful technology implementation. Alternatively, they may choose to use the benefit calculator to evaluate the likely financial benefits that could be gained from improving their environmental conditions through the implementation of PLF technologies.

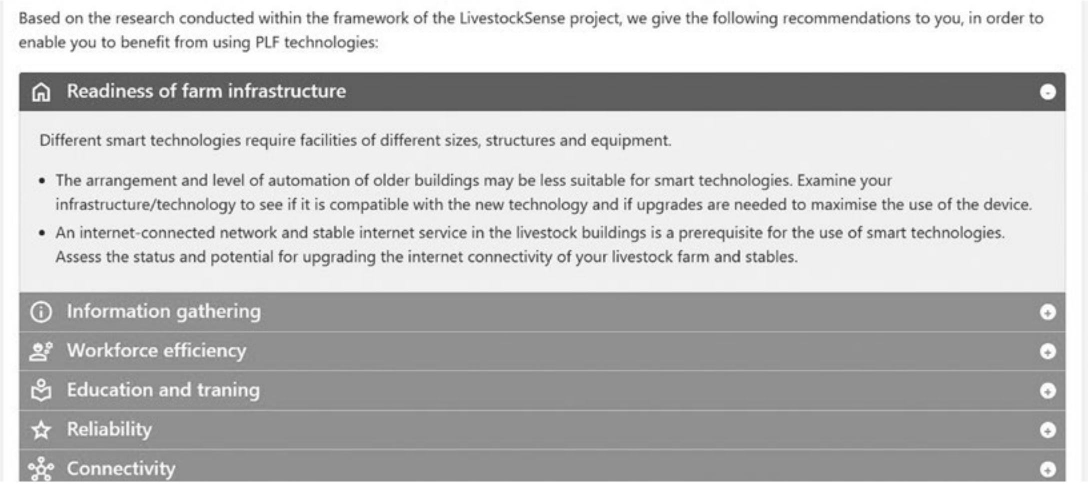
Sub-study 5: ADAMS database developed

The ADAMS system was developed to ensure that the sensor measurements are regularly uploaded and sent to the main Web Application. The Web Application automatically saved the data in a MySQL database after receiving the data string. Both the Web Application and the MySQL database were running on a Virtual Machine in the Amazon cloud. The database application was designed to systematically store, analyse, and visually present data by automatically generating and sending the generated reports via e-mails to users.

Sub-study 6: On farm data collection using various smart sensors and benefit calculation

The 20+ smart PLF devices (Enviro-Detect^{TM} and Weight-Detect^{TM} sensors) deployed on 15 farms in five selected countries (i.e. Estonia, Hungary, Israel, Poland and Sweden) during the research period performed quite well but a number of issues have been identified. For example, while the Weight-Detect™ instruments had an average predictive error of around 3%; a number of other factors, such as animal behaviour, camera placement and farm management influenced their predictive precision (Banhazi *et al.*, 2022d; Banhazi *et al.*, 2022a). Occasionally, the predictive error was higher than 3%. In addition, the correct interpretation of results obtained influenced their usefulness on farms. Internet connectivity was also a major and recurring problem during the study (Banhazi *et al.*, 2022a). Associated overseas studies demonstrated too, that the natural body weight fluctuation of pigs is around 3.2 kg on average, but pigs at a later stage of their growth period can display much larger diurnal body weight fluctuation (Liu *et al.*, 2023). Thus, it is obvious that certain level of imprecision has to be accepted when weighing pigs routinely under commercial conditions. PLF technology users have to learn to use the data captured to their advantage, while accepting the practically achievable measurement precision under commercial conditions (Liu *et al.*, 2023). Another associated study demonstrated that improved thermal control, provision of optimal air quality, and maintenance of health status of animals are all-important factors that can improve production efficiency (Banhazi *et al.*, 2022e; Tikász *et al.*, 2022). These studies concluded that real time monitoring and better controlled production conditions in livestock buildings could result in improved profitability on commercial livestock farms (Banhazi *et al.*, 2022b).

The data analysis (using generalised linear regression models) aimed at quantifying the economic benefits of improving the environmental conditions in livestock buildings demonstrated that reasonable predictions of weight gain were possible on commercial farms from the environmental variables. However, results were highly farm specific. For example, on one farm ammonia interactions with temperature were most influential, while on other farms carbon dioxide concentrations were strongly associated with growth efficiency (Banhazi *et al.*, 2022f). This made it difficult to generate a more 'universal' recommendation for technology users. Hence the results of a previous study (Banhazi, 2013) were used to create the LivestockSense PLF Compass: Benefit Calculator section of the application (https://plfag.info/improvementcheck) (Figure 4).


Based on the research conducted within the framework of the LivestockSense project, we give the following recommendations to you, in order to enable you to benefit from using PLF technologies:

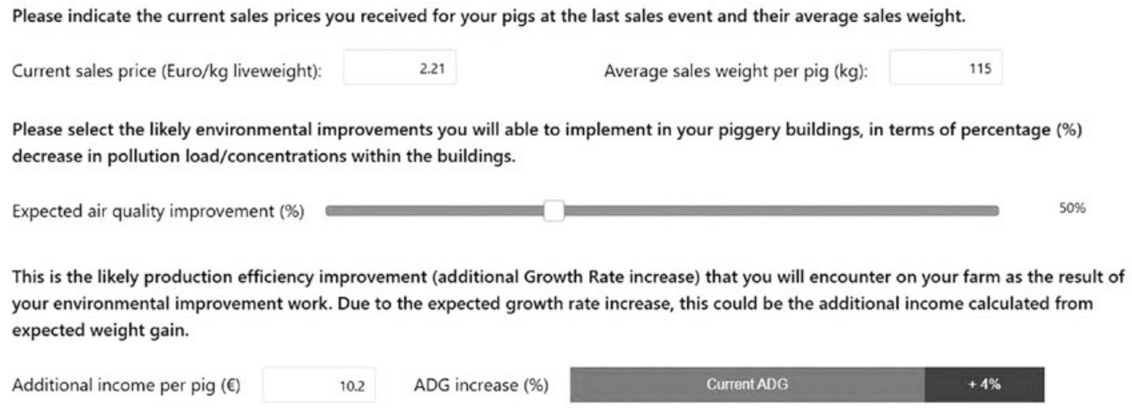
Different smart technologies require facilities of different sizes, structures and equipment.

- The arrangement and level of automation of older buildings may be less suitable for smart technologies. Examine your infrastructure/technology to see if it is compatible with the new technology and if upgrades are needed to maximise the use of the device.
- An internet-connected network and stable internet service in the livestock buildings is a prerequisite for the use of smart technologies. Assess the status and potential for upgrading the internet connectivity of your livestock farm and stables.

Figure 3: LivestockSense PLF Compass: Recommendations.

Note: After the readiness level of the farm has been assessed, specific recommendations can be viewed by users to assist them with technology implementation.

Source: Own composition



Please indicate the current sales prices you received for your pigs at the last sales event and their average sales weight.

Current sales price (Euro/kg liveweight): 2.21

Average sales weight per pig (kg): 115

Please select the likely environmental improvements you will able to implement in your piggery buildings, in terms of percentage (%) decrease in pollution load/concentrations within the buildings.

Expected air quality improvement (%) 50%

This is the likely production efficiency improvement (additional Growth Rate increase) that you will encounter on your farm as the result of your environmental improvement work. Due to the expected growth rate increase, this could be the additional income calculated from expected weight gain.

Additional income per pig (€) 10.2

ADG increase (%) Current ADG + 4%

Figure 4: The main display screen of the benefit calculator.

Note: Producers can indicate their average sales price and sale weights. After that, they can nominate the likely environmental improvement implemented in their buildings (percentage reduction in airborne pollutants, specifically in ammonia and airborne particles) and the software tool will calculate the likely extra sales prices received for their animals as the results of extra production efficiency gained.

Source: Own composition

Sub-study 7: Integrated software/application developed

The final development tasks undertaken as part of the research created an integrated ICT tool to (1) classify/predict the level of technological readiness of users, (2) give advice how to reduce or eliminate the various barriers and (3) predict expected benefits (quantify economic benefits expected from the introduction of PLF tools). This ICT application is currently hosted by AgHiTech and now readily available for use by the general public.

Conclusions

Smart PLF systems are now making data collection on farms both practically and to a large extent financially viable. However, few livestock producers are willing to adopt PLF systems, because they must overcome various barriers before they can effectively use the information obtained (Black and Banhazi, 2022). The findings of this research, derived from a general review, quantitative and qualitative surveys, including focus group discussions (FGD) and roundtable talks, revealed producer motivation tempered by cautiousness due to unproven benefits, pricing concerns, and reliability of maintenance services. Ownership/access uncertainties and rural internet connectivity hurdles were identified as major obstacles (Kopler *et al*., 2023).

Quantitative questionnaire outcomes highlighted that the existing level of automation on the farms, the average age of the livestock buildings (and associated production technologies), the availability of internet connectivity determine the "readiness levels" of livestock producers to adopt smart/PLF technologies (Tikász *et al*., 2023b). FGDs confirmed these issues (Tikász *et al*., 2023a) and underscored the importance of government support programmes/subsidies to alleviate installation and maintenance costs (Olejnik *et al*., 2022a). Recommendations derived from survey results were integrated into the LivestockSense PLF Compass: Advice Generator application component.

The smart PLF devices deployed on 15 farms performed well but internet connectivity was a major and recurring problem throughout the study (Banhazi *et al*., 2022c). Overseas studies demonstrated that certain level of imprecision must be accepted when using PLF technologies under commercial conditions (Liu et al., 2023). However, real-time monitoring and enhanced production control in livestock buildings were identified as key factors contributing to improved profitability on commercial farms (Banhazi *et al*., 2022b).

Generalised linear regression models have been developed to quantify the economic benefits associated with improved environmental conditions in livestock buildings. As the results were highly farm specific (Banhazi *et al*., 2022f), the results of a previous study (Banhazi, 2013) were used to create the LivestockSense PLF Compass: Benefit Calculator. An unsupervised machine learning analysis identified three clusters, indicating different technological readiness levels among farmers considering PLF technology adoption (Mallinger et al., 2023). The outcome of this analysis/modelling was incorporated in the PLF Compass application, providing a comprehensive ICT tool to (1) classify/predict the level of technological readiness of users, (2) give advice how to eliminate the various barriers (3) and predict expected benefits.

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