EU-PLF

PROJECT FINAL REPORT

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Animal and farm-centric approach to precision livestock farming in Europe

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Name, title and organisation of the scientific representative of the project's coordinator[1]:

Tel: +32 16 321726

Fax: +32 16 321480

E-mail: daniel.berckmans@kuleuven.be

Project website address: http://www.eu-plf.eu

[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.

Final publishable summary report

Executive Summary

Before starting the EU-PLF project there were already over 1000 scientific publications and papers on the development of the technology of Precision Livestock Farming (PLF): the real-time monitoring of livestock by using cameras, microphones and sensors. The final objective has been to realise a continuous and fully automated monitoring system to support farmers in managing their animals. Most PLF research so far was done in the laboratory or in farms with laboratory conditions where the concept and the potential was analysed and proven. No installations were operational in commercial farms and the upscaling of the approach was only discussed while never proven. Moreover the technology was unknown to farmers.

A first objective of EU-PLF was to make PLF installations operational in commercial farms for 3 different species: broilers, fattening pigs and dairy. The next was to make these farmers familiar with the installations and analyse how they experience this new technology. We then evaluated the results from the automated PLF system, human experts assessed the animals during each production period using the Welfare Quality protocols as a reference. All these efforts were brought together to realise the main objective, which was to deliver a PLF-Blueprint for farmers on how to install and use this technology.

Six months after the start of the project the camera and sound based installations for real-time monitoring were operational in 10 broiler houses and 5 houses for fattening pigs. Upscaling to real field conditions required solutions for technical issues (like poor internet and pests damages) but in general for the microphone- and camera-based PLF systems, that were selected as ready to go to the field, the technical installations went fast in 15 farms. The installations in dairy took more time due to partner changes in the project but finally also became operational. Technical problems to be taken care of are described in the PLF Blueprint. The conclusion is that non-specialist installers can do the PLF-installations in commercial farms which is important to bring PLF as a service.

Several workshops with farmers were organised for trainings and discussions to get feedback from the users. We experiences that farmers need specific training and guidance to understand the working principles and get familiar with these PLF systems. In general for most farmers the PLF systems brought peace of mind and comfort since they know that the animals are guarded continuously day and night. The economic benefits are yet less clear and different for the different PLF systems. In the PLF Blueprint there are guidelines for farmers and companies to check which or whether PLF systems are appropriate for a specific farm.

In terms of data collection the project generated a huge amount of data collected in 20 farms with 20.000 sound samples and 25 image samples per second. Existing algorithms were used to get relevant information and improved or new algorithms were developed. This give interesting insight in how the big data concept should be applied to the livestock sector.

As shown in published material there were several cases were results from PLF installations were in agreement with the manual assessments by human experts. The camera based system for broilers was shown to detect more than 90 % of general problems (blocked feeder line, light problems, water supply, climate, etc.) by continuous analysis of animal behaviour. It was shown that the sound based continuous monitoring was detecting health problems in fattening pigs from 2 up to 12 days faster than what the farmer noticed.

The PLF-Blueprint is a manual for farmers and stakeholders to get information on how to select and install the technology and check whether a PLF system is appropriate for a specific farm. The Blueprint will be maintained and developed further. Together with the Blueprint is an integrated e-course on PLF aimed for scientists and companies interested to understand the basic principles and ways to develop the technology to a higher level.

PLF technology realises the fastest way to detect a problem in a livestock house by monitoring and analysing continuously the behaviour of the animals to get relevant information from the raw data. Of course the farmer is the first to be interested in this information since he and his family are depending on the health, welfare and productivity of the animals. But there are many other stakeholders who are interested such as veterinarians, feed companies, pharma companies, technology providers, breeding companies, slaughter houses, retailers, the consumer, citizens, local but also national and European governments, the press and researchers. During the project we had many discussions on the possible and applicable business models of the PLF technology since there are so many different stakeholders. Therefore the idea that only the farmers have to pay for the technology is too narrow starting point. If several stakeholders get a benefit from the information extracted from the PLF data owned by the farmer, then part of that benefit has to contribute to the PLF platform and part has to go to the farmer who generates the data. There is no valuable information without data. Farmer's organisations and farmers unions have an important role to play since they might be the ones to offer a contract to the farmer.

It was interesting to experience during the project that the work package with the difficult task to start up 4 new companies in PLF applications was very successful. Many potential starters and young people were trained all over Europe and finally 4 new companies were started in 4 different European countries. The livestock market is indeed a huge market for new technology that can be beneficial to many stakeholders.

One of the most important overall results is the understanding that the use of PLF technology and approach with continuous automated monitoring of livestock has become implementable and realistic in commercial farms. Before the EU-PLF project there were many discussions on how realistic the upscaling of this approach would be. Today we notice that farmers and industry have a totally different vision and are convinced that this technology will go to the market and be very interesting in relation to the Internet of Things. The PLF technology has the potential to be a disruptive technology for the livestock sector and to transfer the livestock sector in an innovative and modern industry. One of the reason why PLF technology can be disruptive is the fact that the worldwide demand for animal products is increasing with 70 % by 2050 and this mainly in countries like China, India, South America and Africa. Disruptive technology is needed to introduce PLF technology there and meanwhile this will make the technology for the European family farmers who aim for a different product than healthy cheap bulk meat.

We are not able to change the trend in the worldwide increase of animal products. The best way to make the livestock sector more sustainable is to produce animal products in a way that we reach more close to the genetic potential of our existing genetic lines. In this action PLF technology plays a major role with innovations such as continuous health and welfare monitoring, individual precision feeding, early warning when animals change behaviours, continuous guarding of the stress of animals and this in collaboration with different stakeholders. To realise this researchers in the first place but also other stakeholders should collaborate in a more efficient way instead of being stuck within their too limited environment, the fast changing world does not allow people to behave in an old fashioned way since the world needs serious improvements to stay liveable.

Daniel Berckmans

Project Coordinator EU-PLF project contract no. 311825

3.0 A summary description of project context and objectives

With ever increasing pressures to exploit the economies of scale, farm intensification and specialization is progressing at a fast pace throughout Europe. Through this phase of consolidation farms are growing increasingly larger, placing higher pressures on farmers to manage many more animals than ever before. Farmers have less time available for caring for each individual animal whilst society demands that animals are entitled to receive individual attention. It is now becoming more difficult for European farmers to continuously pay attention to individual animals, and this is true not only for the production-intensive sectors like poultry and pigs, but also for dairy production. The current situation has social and economic consequences for all stakeholders involved, first and foremost for animals and farmers. Good care is precisely the key for good productivity, health and welfare and thus for an economically viable business. However, state-of-the-art technical support can bring the animals closer to the farmer by assisting the farmer in gathering information about the animals and presenting it in a workable way.

There is now increasing concerns about animal health in relation to human health issues with the potential for pandemic outbreaks continuously looming over the industry. In addition to health, other aspects of animal welfare have become an important point. Today's consumers are more conscious about keeping animals for food production: they should be raised, treated and slaughtered in a more animal friendly way and should have a life worth living. Europe has invested significantly in developing methodologies for assessing animal welfare at farm level (Welfare Quality consortium 2009a, b, and c). However, a large gap exists between methods in animal welfare management and their practical implementation on farms. These methods can further improve animal welfare in intensive and extensive production systems and ensure sustainability only when implemented successfully at farm level.

The environmental impact and environmental load of worldwide livestock production remains a challenge. For example, 90% of NH_3 pollution arises from livestock production (Asman and Drukker, 1988; Dobeic et al., 2011) and 18% of greenhouse gas emissions in CO_2 equivalents come from livestock (Steinfeld et al., 2006). In addition, the total energy used in producing animal products is too high to be sustainable as Europe faces relatively high production cost than other countries who profit from their different climatic conditions, available farmland and low labour costs. Finally, agriculture as well as other human activities shall continue to develop in order to meet societal needs (e.g. in terms of food security in the context of an increasing world population) while preserving the resources for the next generations. To this aim, activities must be managed very precisely in order to increase their efficiency in terms of performance, sustainable use of resources and reduction of negative impacts.

Consumers expect safe but affordable animal products (i.e. meat, milk) and a clean, animal friendly and sustainable production. At the same time, farmers need a reasonable income and social recognition. Information and Computer Technology (ICT) offers a high potential to carry out real time monitoring of individuals, and improve the economic viability of livestock farms. Continuous automated monitoring of the varying needs of individual living organisms has now become a reality. This has been shown in several human applications such as monitoring of patients in intensive care units, monitoring an ageing population, pain monitoring in elderly people with dementia, performance monitoring in sports. To apply the high potential of these ICT technologies in livestock production is the core idea of Precision Livestock Farming (PLF). Continuous automated monitoring of agricultural animals results in "early warning systems" that improve the management of (individual) animal needs at any time. Similar to human applications, modern technology can ensure more attention and care to the (individual) animal in a large system. PLF also offers potential to monitor and reduce environmental impact.

Being the forerunners/pathfinders in the vision of adopting PLF for the creation of value, European scientists from this EU-PLF consortium have started the European Committee for Precision Livestock Farming in 2003 during the first European Conference on Precision Livestock Farming. Since then, this committee has organised 5 European Conferences on PLF (namely EC-PLF 2003 in Berlin, Germany; 2005 in Uppsala, Sweden; 2007 in Skiathos, Greece; 2009 in Wageningen, the Netherlands and 2011 in Prague, Czech Republic) and the 6th European Conference will be held in Leuven, Belgium Sept 10 – 12 in 2013 (Werner and Jarfe, 2003; Cox S., 2005 and 2007; Lokhorst and Groot Koerkamp, 2009; Lokhorst and Berckmans, 2011). Beside these 5 EC-PLF conferences, the PLF society has organised 4 Smart Sensor Workshops (Silsoe UK 1997, Bremen Germany 2001, Leuven Belgium 2007 and Gargnano Italy 2009). The Bright Animal Project has Organised 5 Workshops (Halifax, England: May 2009; Tartu, Estonia: May 2010; Copenhagen, Denmark: May 2010; Johannesburg, South Africa: September 2010 and Barcelona, Spain: March 2011).

Conclusions of the 5 EC-PLF conferences, 5 Bright Animal Conferences and 2 Biobusiness workshops held until 2012.

1. It has been demonstrated that PLF Technology has a significant potential to automate the continuous measurement of key indicators on farm using modern technologies such as image analysis (video recording), sound analysis (audio recordings) and novel sensors. Image and sound analysis have the advantage that the animals are not in direct contact or otherwise affected by the technology

2. To date most of the research has been done at laboratory level or research facilities and now is the key moment when PLF systems are ready to be used day to day on commercial farms. This is a strategic moment where research can be translated into industrial application. Results from on-farm technology applications show that commercial products require a combination of hardware complying with certain technical and safety standards regarding packaging and housing, a combination with software, a good user interface, a backup solution to store data, an auto-restart function in case of power failure, manual and help functions, installers who can install and service the product, good understanding of how the use the outcomes in daily management, training for the farmer, etc.

3. As scholars in different disciplines often work in an isolated manner, most results and findings of PLF technology are unknown to animal scientists, veterinarians, ethologists, while most PLF experts have poor understanding of the needs of the other groups. All scientists are very much focused on their “world” of journals, conferences, workshops etc. However, a combination of new technologies with biology offers great opportunities through synergy effects for European animal production in terms of realising and implementing directives as well as in economic and social terms (e.g. welfare quality assurance, ID chip for animals to improve disease control and containment).

4. Due to a lack of implementable and operational installations at farm level, there is too limited data that relates sensor signals to key indicators on farms. Consequently, whilst there are strong indications and scientific proof that PLF automatically creates value, there is little knowledge from on-farm applications on how PLF can create value for the different stakeholders and end-users. To promote insight in how a continuously monitored animal based sensor signal translated into a key indicator (for example “coughing” of fattening pigs translated into a health indicator) can create value for the animal and the farmer (for example by reducing veterinary costs and loss of production), field data of operational systems must be collected on farms. Only the analysis of data collected directly on farms can give the final

confirmation to convince farmers that monitoring key indicators brings value to the livestock industry.

5. Innovative technologies create high potential provided the implementation cost can be kept low or the provided returns are high. Cost of newly developed technology is highly dependent on production volumes (e.g. Mobile phone technology became available to consumers after 20 years of existence thanks to the low cost of mass production). The numbers of animals in livestock production are very high (this year there are over 50 billion animals slaughtered for worldwide food production). This potential market for ICT technology in the livestock business is fairly unknown to innovative and technology driven high tech SME's and they hardly know how to access this consolidating but still highly fragmented market.

6. To explore the potential of livestock applications with new technology innovative high tech SME's should be linked to global industrial market players in the livestock sector.

7. It is not clear how high-tech SMEs and existing market players and suppliers in the livestock market can be linked in a win-win collaboration and which business models can be applied to create further adoption of PLF. The farmers like all other users of technology want a service and solutions for their problems without becoming technology experts themselves.

8. So far, PLF has mainly been a "European discipline" although now scientists in the USA, Brazil, Australia and China are starting several initiatives and research projects themselves in this field (ASABE 2010; Banhazi and Black, 2009; Banhazi and Black, 2011).

9. The EU has funded several animal-welfare studies that identified criteria for scoring animal welfare (Blokhuis et al., 2010). A difficulty in the application of on-farm assessment of these criteria is the time and effort needed for completing farm visits to realise a complete assessment on a farm and the possible subjective bias of humans performing the manual scoring or measurements. It remains challenging to improve the life of animals based on a limited number of farm assessments in time. Modern PLF technology can bridge this gap. Moreover PLF technology allows not only the automated continuous monitoring of (individual or groups of) animals, but it can also deliver integrated solutions to actively improve the life of animals during the production cycle and by doing so create social and economic value for the farmer.

Given this context the EU-PLF project had the following objectives:

- Define and create **a validated blueprint** to realise an animal and farm-centric approach to innovative terrestrial farming in Europe. This Blueprint could be then used as a "manual" with available website support, describing how to turn PLF technologies into implementable and operational systems at farm level and how to use these technologies to create value for animal, farmers and other stakeholders in the food chain.

- To apply PLF successfully we need to define **Key Indicators** at farm level and corresponding **gold standards**.

- Create a set of Key Indicators that allow capturing quantitative information directly from the animal or its environment in the domains **animal welfare**, **animal health**, **environmental load** and **productivity**. Besides these Key Indicators, their gold standards will be defined in order to access their validity. By extensive field tests it will be analysed how these Key Indicators on farm relate to social and economic value measures to quantify the value creation by applying PLF technologies.

- Carry out an SME-drive to include a total of 50 selected SME's and about 50 end users (farmers) in the EU-PLF activities. These identified high tech SME's or potential starters will be informed about the potential for them to innovate the European Livestock market by bringing their high tech products into PLF systems that can be commercialised by existing market players. Moreover they will be challenged and encouraged by a competition to realise the idea of "PLF as a service".

The validated Blueprint is the main outcome of the EU-PLF project, should be useful *for all stakeholders with a focus on farmers and the servicing industry including SMEs* since they are key players in integrating new technology into European livestock production systems. Stakeholders have been defined as the animals and farmers, veterinarians supporting the farmer, industrial companies delivering feed, medication, equipment and installations to the farmers but also high tech SME's, slaughter houses, retailers, consumers, the general public, press and media, government from regional to European level and scientists from different disciplines.

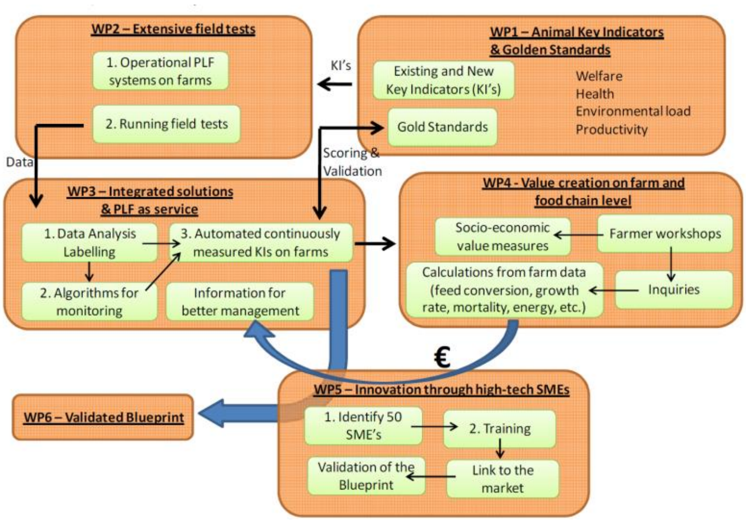
4.0 Main Scientific and Technical results

4.1 Overview

The EU-PLF project was divided into eight work packages (WPs). The overall aim was to design a Blueprint for farmers and other stakeholders that shows how PLF technology could be best developed and implemented at farm level in order to support improvement of productivity, animal health and welfare, and reduce environmental emissions and energy use.

WP1 was focussed on the definition of a set of existing and new key indicators by experts in the four domains of animal welfare, animal health, environment load and productivity. All key indicators had a corresponding gold standard, which were then used as part of PLF system design and validation. **WP2** then defined and selected implementable PLF systems to measure key indicators at farm level, selected appropriate test farms (20 in total), made the systems operational and collected data during extensive field studies. The project covered about 20 fattening periods in total for pigs and broilers and 1-2 lactations on the dairy farms. In **WP3**, the bio responses measured at farm level will be related to the key indicators in the four domains via PLF technology. Here algorithms were developed to automatically quantify the key indicators of these four domains (score/algorithm), using the gold standard as a reference.

WP4 determines ways to calculate social and economic values from the data collected on farm. In this WP farmers were involved through workshops to collect information on social values, and calculations of social & economic value measures for the 20 involved farms were done. WP5 then analysed how the continuously key indicators measured on each of the 20 farms related to the social and economic value measures of that farm. This information was then fed back to **WP3** to define and develop integrated solutions to make this information useful for the farmer and the value chain. During the project **WP5** identified high tech SME's and potential starters for the world of the intensive livestock production. They were educated on the PLF approach and opportunities on how their technology can offer new PLF developments were explored. Through an open competition, funding for PLF prototype development was made possible, and 4 spin-off companies were created and trained to commercialise new PLF systems. The context for the successful usage of the PLF technology and its applicability was described in form of a blueprint (**WP6**). The project results will be disseminated to explain to farmers how PLF can work in their economic benefit and improve their relationship to the individual animal (**WP7**). **WP8** coordinated the project management.



Work package structure of the EU-PLF project.

4.2 WP 1: Animal Key Indicators and Gold Standards

4.2.1 Work carried out during WP 1

- Determine existing animal key indicators and golden standards
- Define and investigate new KIs that can be measured with PLF
- Train regional people to apply golden standards and application of gold standards in field tests

A complete list of current key indicators (KIs) and gold standards has been developed by experts in the consortium for the four domains (animal welfare and health, production and environmental load) in dairy and broiler pig production. These were defined during technical meetings between relevant experts, by recourse to literature and synthesis of outputs from EU projects such as Welfare Quality and the European Animal Welfare Platform. In relation to each defined KI in the different domains a reference method for determining the value of that indicator at farm level was defined. Gold Standard (GS) were used in WP3 as a reference to test and validate the performance of the PLF systems when measuring these KI's at farm level. The list of Key Indicators and Gold Standards in relation to the four different domains for all species included in this project were published in Deliverables 1.1 and 1.2. Also possible technical solutions that could have the potential to be able to measure the Key Indicators in an automatized way were indicated.

Definition of new KIs that can be measured with PLF

This task investigated how the specific PLF technologies (image, sound, and location) could be used to quantify new KIs that had emerged from previous research studies, and be linked to gold standards. The selected PLF techniques were then implemented on the experimental farms, e.g. at SLU and INRA. The work thus focus on existing technologies and further develop their application for on farm use and implementation. The PLF techniques will be applied to a small group of animals and extensive testing applying GSs were performed. The results of these investigations are outlined in the following text.

<u>DAIRY</u>

Detection of new points of interest in the barn

The CowView positioning data from 190 cows were logged during 123 consecutive days. This dataset was converted into a unique density image on a virtual map of the barn. Each pixel gives the accumulated time spent by all the cows on a given 1 cm^2 spot. Spots of interest are represented by a high intensity colour (**Figure 1**). In addition to the zones already detected by CowView at the start of the project (e.g. cubicles where cows spent a high proportion of time), we could identify new spots of interest and they were matched with specific features of the environment such as brushes or mineral blocks. Once a spot was empirically highlighted, the occupancy, i.e. the exact time cows entered the spot and how long they stayed in, were extracted from the database and compared to the behaviour recorded from video (gold standard). We could then relate the use of a spot to a specific activity (e.g. brushing the head or the back, licking a mineral block). The sensitivity of the detection of these new activities is at least 80%. These news activities can thus enrich the information from existing PLF systems based on Real-Time Location Systems (RTLS).

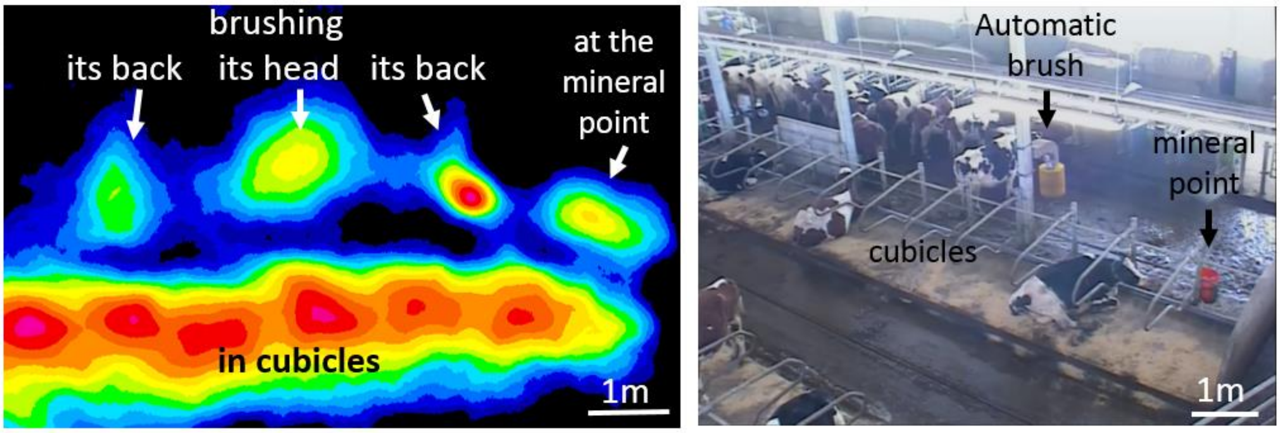


Figure 1: Spots of interest identified by the density image (a hot colour indicates a high level of occupancy by cows) and validation using video snapshots

Description of cows' daily rhythm of activity

To determine the overall activity and its variations during the day, we used the hourly accumulated basic activities of each individual cow as determined by the CowView system, i.e. time spent resting, eating, or in alleys (walking or standing) during each hour of the day.

We attributed a weight to each activity, from a factorial analysis of correspondences. The four activities obtained the following weights (on average on different farms monitored): -0.16 for resting, 0.10 for standing, 0.11 for walking, 0.31 for eating. Then we calculated the overall activity of each cow during each hour x day. This allowed us to highlight a circadian rhythm of activity, with in general one morning and one evening peak and low activity at night (**Figure 2**). Finally, we calculated two descriptors for each cow and day: the average activity during the day and the size of circadian variations (the standard deviation between hours of that day).

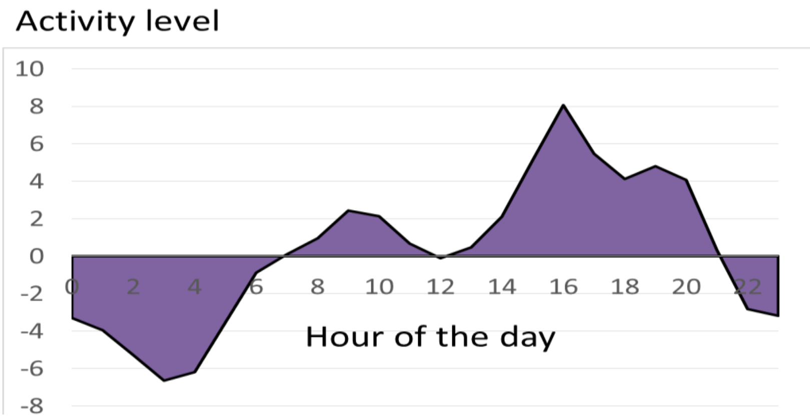


Figure 2: Daily variations in overall activity

Variations in individual cow activities

We compared the 24 h time budget of cows from different farms, that is the distribution among the basic activities of cows (time spent in alley ways, at feeding table, in cubicles and in the milking waiting area), together with the distance travelled. We observed two large dairy herds for 7 days.

Despite differences in production facilities (e.g. automatic vs. conventional milking, group sizes, and feed) the cows had similar time budgets in the two herds, which makes us to consider the time budget a robust variable across farms. Actually, variations in cow time budgets were smaller between farms than within farms, which led us think that these may be due to changes in the state of the cow (oestrus, disease). Then we focused on short-term changes in cow time budgets in relation to time of insemination to investigate oestrous behaviour in the same two farms. Changes due to pro-oestrous and oestrous behaviour were most distinct on the day before insemination and most marked for time spent in the cubicles (which was decreased) or in the alleys and distance travelled (increased). The changes were more distinct in the farm with conventional milking than in the farm with automatic milking. Finally, on three new farms, we investigated potential changes under naturally occurring mastitis and lameness disorders. We looked at the behaviour and milk production of cows in relation to time of disease treatment, ± 10 days for mastitis, and ± 15 days for lameness cases. In mastitis, the response included milk yield loss, reduced time resting and eating, and increased time spent in the alleys. Only very small changes in short-term activities were seen prior to lameness treatment (increased resting and decreased eating times). These variations were however not significant, probably due to large variations between days. In addition, large variability was seen between farms, especially for mastitis, which could be due – among others - to differences between primary pathogens and / or disorders, disease severity and clinical course of the diseases.

Average activity level and circadian variations

We observed significant differences in average activity level and its variations during the day between control days and days when a specific animal state was detected by the farmer: oestrus, lameness, or mastitis (other disorders were not frequent enough to run analyses) (**Table 1**). Cows were more active and showed less marked within-day variations when oestrus or mastitis was detected (d-0). In the case of oestrus, we observed similar changes in activity level and its variations on d-1 but not on d-2 where circadian variations increased. In the case of mastitis, no hyperactivity was observed on d-1 and d-2 but there was less activity variation. In the case of lameness, we observed a slight decrease in activity and a decrease in circadian variations. The circadian organization of cow activity thus seems sensitive to the physiological or pathological state of the cows. These first results need to be confirmed so that thresholds can be defined above which alarms are sent to farmers.

Table 1: Changes in overall activity and its variation in relation to oestrus, mastitis, and lameness

	Oestrus	Mastitis	Lameness	Control	P-value
On the day when the event was detected by the farmer(d0)					
Average activity	2.34	2.26	0.07	0.28	***
Standard deviation	13.78	11.7	13.7	14.5	***
On the day before the event was detected by the farmer (d-1)					
Average activity	2.96	-0.32	0.32	0.27	***
Standard deviation	14.06	12.7	14.2	14.5	***

On 2 days before the event was detected by the farmer(d-2)					
Average activity	0.69	-1.49	0.44	0.26	*
Standard deviation	15.2	12.5	14.4	14.5	***

Location monitoring as a response to induced SARA

Subacute Ruminal Acidosis (SARA) is a very common digestive disorder in high producing animals, especially dairy cows that receive high energy diets. These diets induce a rapid release of volatile fatty acids in the rumen, in turn decreasing ruminal pH and disturbing digestion, which can have a negative impact on milk production. We induced SARA in 14 experimental cows by providing them with a diet containing 30% starch for 3 weeks and we compared them to 14 control cows receiving a diet containing 10% starch. Before and after the 3-week SARA challenge, all the cows received the same diet (10% starch). The SARA status of cows was checked using an eCow intra-ruminal bolus. Under SARA, the cows were significantly less active – as detected by CowView -, especially after the morning meal (**Figure 3**). We also investigated the time the cows spent licking the mineral blocks (following the image analysis presented above). The cows under SARA spent more time licking the mineral blocks. These promising results were obtained on a small sample of cows and with a specific diet and need to be confirmed in various nutritional conditions.

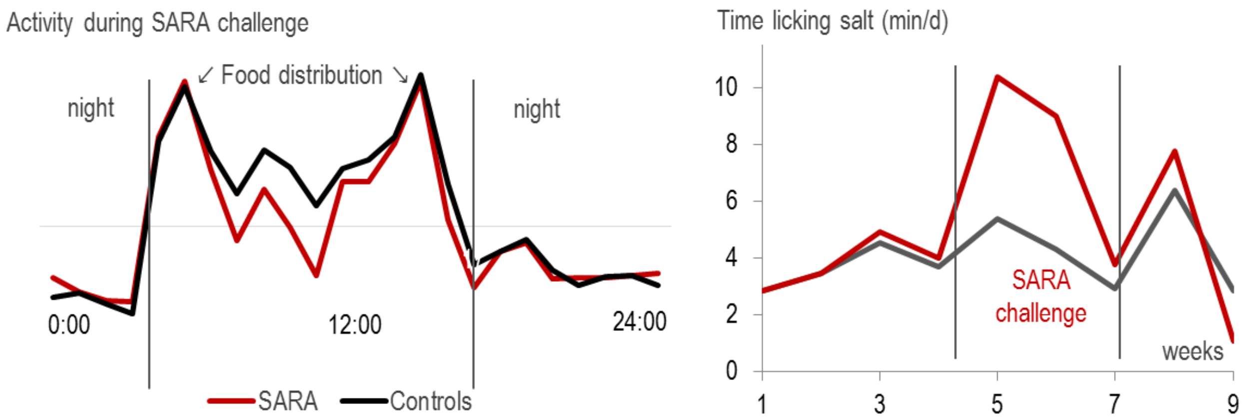


Figure 3: Modifications of cows' behaviour under SARA. Left, circadian variations in overall activity level. Right, time spent licking mineral blocks

<u>POULTRY</u>

Testing Human-Bird relationship

In poultry production direct physical contact between human and animals might be considered from the birds' perspective as positive, neutral or negative. Negative responses are mainly connected to fear, which is the natural response to a potentially harmful situation or presence of a predator species. Notwithstanding the reduced physical contact between the farmer and the broiler chickens, the human-animal relationship is an important welfare indicator due to the effects that the human-animal relationship has on welfare and productivity. The Touch Test (TT) is often used as a method to assess the human-poultry relationship, where the avoidance behaviour of the birds to an approaching human is tested. This kind of welfare assessment, performed by trained persons, can be resource demanding, with regard to both time and money. Moreover, the visit of an assessor to different farms also presents a bio-security risk. The commercially available eYeNamic™ system (Fancom BV, The Netherlands) was used during the project to evaluate whether changes of broiler activity, in response to the presence of the stockperson, could predict the human-animal relationship in commercial broiler flocks. EyeNamic™ uses cameras mounted in the ridge of the house monitoring continuously the floor below. The integrated analysis software translates these images into an index for animal migration and activity, enabling to follow the behaviour of the flocks during the interactions with human assessors. (**Figure 4**)

The presence of a moving human challenges the birds to cause changes in their locomotor activity leading to activity changes related to the human-animal relationship. The birds' direct response to an approaching human was interpreted as a high level stress indicator, and the results from this study show the potential of using automated image analysis techniques to assess certain aspects of welfare in commercial broiler flocks and thus be of use in animal welfare assessment schemes (Silvera et al, 2016, Draft).

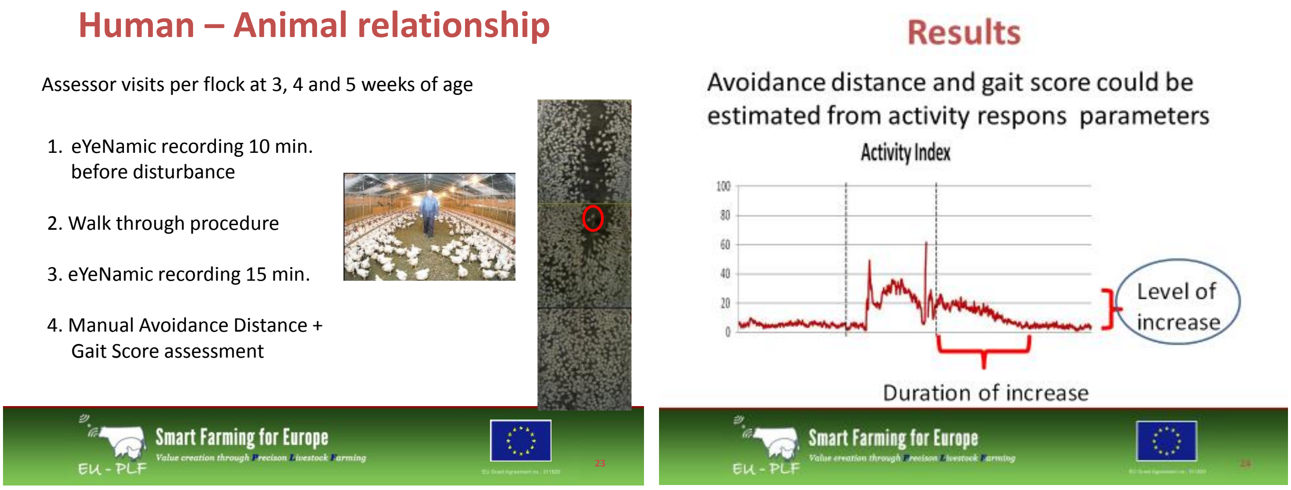


Figure 4: Outline of the procedure and results of automating the distance avoidance test

Bird activity and environmental emissions

The project was also focused on the possibility to control emissions from broiler farming using PLF technology. Indeed, poultry farming is one of the livestock farming system with the higher production of bio-aerosols. The aim of this section of the project was to establish the link between the bird activity and the aerosol concentration. Initial results showed a relationship between the broiler activity and the aerosol concentration. Thus, animal activity, continuously measured using EyeNamic™ system, could be considered as an indicator of aerosol concentration. (**Figure 5**)

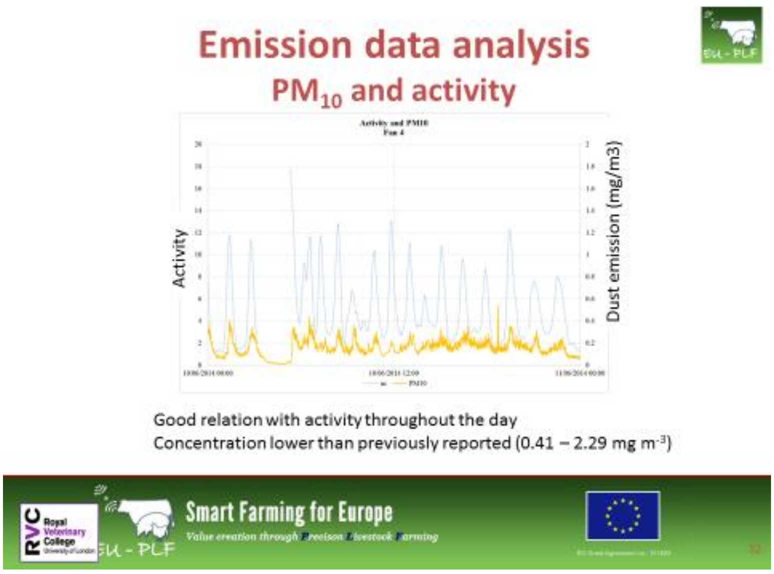


Figure 5: Demonstrating the link between bird activity and PM10 emissions from a broiler house

Sound frequency analysis for production performance

A further aspect of high importance in a broiler farm is the growth trend of the flock, since it is an important part of modern broiler production representing the efficiency and profitability of the processing plant. The average weight of the flock is generally evaluated either manually or automatically using samples of birds chosen at random within a poultry house. The manual measurement of the weight of a representative number of animals in a building is time and labour intensive, since buildings may hold up to 50k birds. Today, many farms use "step-on scales" placed on the floor of the poultry house to automatically collect the average weight of the birds in the flock.

Even if the weighing system gives an accurate weight value each time a bird steps onto it, the weight is only representative for the birds that access the automated weighing system and certainly not representative for all the birds in the flock. The accuracy of automated weighing is limited due to (a) the reluctance of heavy birds to visit the weighing scale (which requires the bird to climb up onto the scale) at the end of the production period and (b) the walking ability of fast-growing broilers that decrease with age, reducing their mobility and willingness to move. Moreover, sick, lame and very heavy birds reduce their locomotor activity, and extend the time periods spent in resting and lying behaviour.

Therefore, while current automatic weighing systems reduce time wasted by the farmer for manual weighing of birds, they may fail to continuously follow the growth trend of the whole flock, whilst simultaneously not estimating the weight of sick, lame and very heavy birds that are reluctant to move and to jump onto the automated scale. During the EU-PLF project, the use of sound recordings collected with the commercially available SoundTalks® monitoring system, allowed to find a clear and inversely proportional relation between Peak Frequency of the sounds emitted by broilers and their weight. A clear relation between weight and vocalization frequency was found, leading to a study focused on the prediction of the growth trend according to changes in peak frequency of the sounds emitted by the broilers. The results indicate that modelling the growth trend as a function of the peak frequency of the sounds emitted at farm level was proven to be reasonably accurate (Fontana et al, 2015). This variable can be used to estimate the performance of the round, as shown below in **figure 6**.

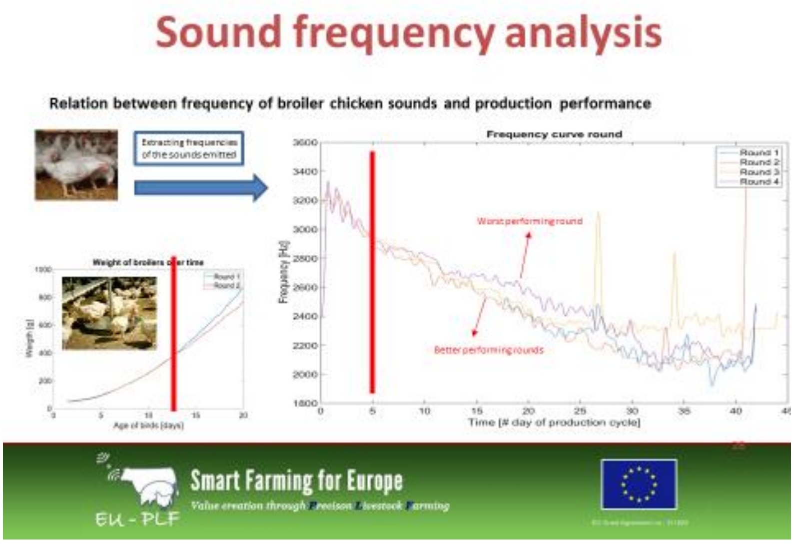


Figure 6: Demonstrating the link between growth and production performance in a broiler house

Training regional people to apply golden standards and application of gold standards in field tests

During this task periodic assessments were carried out at the farms where PLF technologies were installed. The results of these assessments were then used as Gold Standards during PLF algorithm development. Local assessors were trained in animal outcome measures and the use of the KIs on farm. The trained assessors came from institutes local to the farms where the PLF systems were set up. Training and validation of performance was centralised in this task to ensure the KI assessments could be used to make comparisons between and across farms and countries. For fattening pigs was decided to perform a full Welfare Quality® assessment on two farms in Spain and focus on assessing tail biting, wounds on the body, lameness and coughing/sneezing on the other eight farms in different countries in Europe. For broilers the assessors for the broiler farm visits have been recruited and trained for each country where farms were set up with camera and microphone systems: UK (2), Italy (1), Spain (1) and The Netherlands (1).

4.2.2 Impact on other Work Packages

The results of WP 1 were used as an input for WP 2 and WP 3. The KIs that emerged from this WP contributed to the final choice of PLF-technologies that were further developed in the project. This WP also realised the identification and implementation of gold standards that were used in the PLF system development during this project.

4.3 WP 2: Extensive field tests

4.3.1 Work carried out during WP 2

- Selection of implementable systems (PLF-systems) to measure animal responses that relate to KIs in the four different domains (welfare, health, environmental load, and production)

- Selected PLF-systems operational on different farms

- Data collection during extensive field tests on 20 farms

In this WP the sensors and sensing systems were selected to measure the identified KIs. This resulted in an overview of technologies that can measure animal bio-responses according to the KIs determined in WP1. The selected implementable systems were:

- eYeNamic to measure animal activity and distribution
- Sound monitoring
- Feed monitoring
- Climate (temperature, humidity, ventilation rate, CO2)
- Bird weighing (poultry) or eYeScan (pigs)
- Water monitoring
- Real-time location monitoring of cows (Cow-View GEA)

Overview of technologies selected during EU-PLF

Dairy: Many PLF systems have been developed or are under development to help the management of dairy farms. Indeed, dairy cows require close care due to their high production that put their health and welfare at risk. Our objective was to work with existing sensors and systems in order to develop these systems and the modelling behind the output in order to ensure both production efficiency and the welfare of cows. The dairy farms monitored were equipped with several PLF systems. In EU-PLF, we focused on CowView and CowScout, both under development by GEA. CowView is a Real Time Locating System (RTLS). Briefly, the cow's position is determined and its activity is inferred from this position: resting if in a cubicle, eating if near the feeding trough, walking or standing if in alleys. The distance walked by a cow per day is also calculated. At present CowView is used by farmers to know where a specific cow is and if a cow is hyperactive or hypoactive (based on the four basic activities and the distance walked). CowScout is an accelerometer system that, when applied to the leg of a cow, provides information on whether a cow is walking, standing or lying. All these systems provide information at individual level, contrary to those generally used for pigs and poultry.

These PLF systems were coupled to systems already existing in the farms or to video recordings, in order to either validate CowView or CowScout, or to include the data provided by them to other sources of information to refine e.g. prediction of feed intake. At Teagasc, the SoundTalks system was used to record all sounds emitted by calves**. Validating CowView using video data.**

Video validation of the GEA CowView system was performed to evaluate the system's ability to track cow positioning in the respective barn zones and the classification of cow behaviour into standing in alleys, walking in alleys, eating, resting, and drinking. Two rounds of video recording were performed in one test installation, on 5 focus animals in their normal barn environment. The first round revealed lower performance than expected (**Table 2**).

The CowView system configuration was then optimized and a second round was performed. Thanks to this optimization, we reached an overall accuracy over 90% for all activities.

Table 2: Accuracy of CowView to detect cow activity

	Overall accuracy, %				
	Standing in Alley	**Walking in Alley**	**Resting**	**Eating**	**Drinking**
1st round (90000 s)	76	93	79	96	Not assessed
2nd round (132000 s)	92	96	97	97	97

Validating CowScout® against IceTag®

To validate CowScout's precision in determining lying in dairy cows, 30 cows were fitted with CowScout system and the already validated IceTag system (gold standard). CowScout reports standing and lying in 15 min batches whereas IceTag loggers report standing and lying every second. Therefore, the IceTag data were first summarized into 15 min intervals. The data from these two systems were then merged for analysis (more than 1000 cow days in total). A Spearman correlation analysis showed that the lying duration obtained by the two systems very significantly correlate ($r = 0.94$, $P < 0.001$). Thus validating the use of CowScout to detect lying vs standing. The correlation for the number of steps is lower ($r= 0.74$, $P < 0.001$), and this might be due to the two systems probably measuring steps differently. When used together, the CowView and the CowScout system can generate additional data in relation to the comfort of lying areas by measuring the delay between a cow entering a cubicle and its lying down and the exact time spent lying down.

Poultry: The European Union (EU) has recently invested large sums of money in the Welfare Quality® project, which aims to develop a methodology to score animal welfare on farms based assessments by human experts (www.welfarequality.net). The EU regulation specifies that all chickens on the farm must be inspected at least twice a day. Special attention should be paid to signs indicating a reduced level of animal welfare and/or animal health. The challenge in the EU-PLF project was to apply these monitoring requirements in a fully automated and continuous way.

The camera-based technology (eYeNamic™) was used to analyse the behaviour in broiler house according to the activity and distribution patterns that chickens show during each day of the production cycle. Through this system it is possible to monitor the flock behaviour in a continuous and automated way in the house with the aim of understanding the activity and distribution patterns of the flock. The monitoring of activity and distribution indexes allowed the evaluation of the evolution of the flock behavioural patterns, such as feeding, drinking or resting along the cycle.

Pigs: Pig producers are globally facing difficulties that are often beyond their control. The increased cost of feed, the stronger consumers' demand for improved animal welfare and environmental sustainability, the challenges associated with government regulations, the lack of skilled and technically able staff the increasing worldwide competition for agricultural markets are new challenges that can significantly reduce the profitability of traditional livestock production. Pig industry needs new management strategies and new tool in order to remain profitable. In the past two decades several new technologies were developed by different research groups that function automatically and optimise the production environment with the aim of providing up to date real time feedback to farmers about different aspects of their enterprises. Profitability in pig farm is measured considering different aspects, such as the weight, the health the welfare of the animals, and the proper housing management. During the project, the same technologies used in poultry were used also on pigs to investigate the possibility of PLF technology used as early warning in relation to important topics such as pig welfare, health and behaviour.

Respiratory pathologies are widespread in intensive pig farms; their incidence and prevalence are high and their principal clinical sign is coughing. The importance of these diseases must be viewed from an economic as well as a hygiene perspective; veterinary intervention can be expensive and farmers can experience substantial profit losses due to high mortality rates in growing/fattening pigs (which can be as high as 15%) or to a drop in production as a result of reduced feed conversion and a lower growth rate. Furthermore, there is an increase of the concern expressed by consumers regarding the welfare of animals and the antibiotic resistance, in animal-derived products. One of the aims of the EU-PLF project was to verify if automated system were able to identify as early as possible health and welfare problems and let the farmer promptly react, in order to reduce the use of drugs and medications. It has been shown that pig vocalisation is directly related to pain and it is also common practice among veterinarians to assess cough sounds in pig houses for diagnostic purposes. Therefore, during the EU-PLF project an automated cough monitoring system was deployed in order to detect automatically the presence of respiratory diseases. The hardware used to capture the sounds was a SoundTalks' sound recording device. Recordings were continuous (24/24, 7d/w). Capturing sound with a microphone is contactless, does not depend on lighting conditions (these pose a real problem for many cameras in practical conditions), allows the monitoring of large groups of animals with a single sensor, is relatively cheap, does not need a direct line of sight, copes with a wide range of temperatures, can be used indoor and outdoor and has an acceptable lifetime (several years). The system used during the project is able to detect respiratory problems through continuous and automated cough detection.

The long term weight and environment monitoring equipment was installed on 4 farms carried in two European countries by PLF Agritech EU. The pens monitored were located in traditional grower-finisher buildings with either natural or mechanical ventilation systems. In each pen a Weight-Detect^{TM} equipment and one Enviro-Detect^{TM} device were installed in the same building space. Weight-Detect, a contactless imaging system, was used that reliably segment multiple animals from the background to estimate live weight. Scale weighing is not frequently used by farmers due to animal stress caused by scale weighing, high labour and infrastructure costs. However, PLF Agritech's contactless weighing system has the potential to assess the weight gain of animals continuously and stress free. Enviro-Detect^{TM} analysed air quality by monitoring ventilation rate, temperature, humidity and CO2 levels in order to specifically detect changes in environmental conditions.

Keeping systems operational and data collection

To demonstrate the potential of PLF systems on the farms, eYeNamic and Sound Monitoring were implemented on in total 10 fattening pig farms, 5 broiler farms and 1 calf farm. Most of these farms were already equipped with climate sensors, feed monitors and weighing systems (broilers). The farms were selected by the technology providers (Fancom, SoundTalks, PLF Agritech and Royal Veterinary College), based on a number of selection criteria.

In each farm, dependent on the species, a number of selected KIs, representing at least one of the domains welfare and health, environmental load and productivity are monitored by the implemented systems. The systems that are used are eYeNamic (FANCOM, broilers, pigs), Sound Monitor (SoundTalks, pigs, broilers, calves), dust and ammonia monitor (RVC, PLF Agritech, broilers), pig weight, feed supply, dust and ammonia sensor (PLF Agritech, Pigs).

We ran field tests in 6 commercial dairy farms and 2 experimental ones. A total of 2300 cows were followed during 1 or 2 lactations (**Table 3**). In addition, tests were done on dairy calves in one experimental facility.

Table 3: Field tests run in dairy farms

Country	Partner	No. farms	No. cows	No. lactations	PLF systems used in the project
Sweden	GEA	1	205	2	CowView, CowScout, IceTag
Denmark	GEA	2	488 429	2 2	CowView CowView
Germany	GEA	1	595	2	CowView
The Netherlands	GEA	2	238 122	2 2	CowView CowView
France	INRA	2*	160	2	CowView, Biocontrol, eCow, automatic weighing scale
Israel	ARO	1*	100	1	CowView, Cow individual Feed intake and weight, AfiLab

*Experimental farms from INRA (France) and ARO (Israel)

4.3.2 Impact on other Work Packages

Data collected during WP 2 were used as an input for WP 3, the development of the on-line algorithms for PLF systems.

4.4 WP 3: Data analysis, Integrated Solutions and PLF as a Service

4.4.1 Work carried out during WP 3

This work package was aimed at processing the data collected from the operative systems and developing algorithms to automatically and in real-time translate measured animal bio-responses to certain key indicators defined for the four domains.

The WP was divided into the following tasks.

- Labelling and analysis of collected data
- Develop algorithms for automatic detection of KIs
- Develop integrated solutions that translate the signals of PLF-sensors to useful alerts or control action

Data analysis, modelling and algorithms developed

<u>DAIRY</u>

Dynamic modelling of individual cow activities

In order to deal with short term spontaneous variations between days, the trends over days were modelled. On the one hand, a monitoring approach for each individual variable was tested in order to relate sudden changes in the variables to health disorders. On the other hand, the relation between milk yield and the CowView behavioural variables was tested in order to check the impact of the activity in the milk yield. By applying Dynamic Auto-Regression (**DAR**) techniques, the time evolution of each behavioural activity and the milk yield from each individual cow was determined. By using the data from the past 5-7 days it was possible to forecast the behavioural activity for the following 2-3 days. Therefore, deviations between the measured and predicted values (e.g. of 15% or higher), can be used as an indication of a change in the health status of an individual cow in the herd. At the same time, using Single Input-Single Output (SISO) discrete Transfer Function (**TF**) models, the relation between the behavioural activities and the milk yield production could be established for each individual cow. Depending on the lactation number in which the cow is, the order of these TF models varies. Cows in the first lactation exhibit higher order models than cows in further lactations. Work is ongoing to check if the order model for a cow can be used as a predictor of its longevity.

Modelling of average activity level and circadian variations

As for the basic activities, the changes in the descriptors of the circadian rhythm of activity were modelled. By applying the DAR technique, we found that after gathering a week of data, it is possible to daily compare the forecasted value with the real gathered activity level and raise an alert if the deviation between the two is higher than a given threshold. In some cases of mastitis, it was possible to detect anomalies 4 days before clinical signs were detected by the farmer (**Figure 7**)We applied the same technique on the size of circadian variations. Work is ongoing to combine both measurements and the trend evolution determined by the DAR modelling. The outcome is expected to make the early warning tool more accurate, avoiding too many false positive alerts. The level of the threshold to identify deviations from expectations, as well the type of response, is still under study. Indeed, each health disorder is likely to have a different impact on the average activity of the cow.

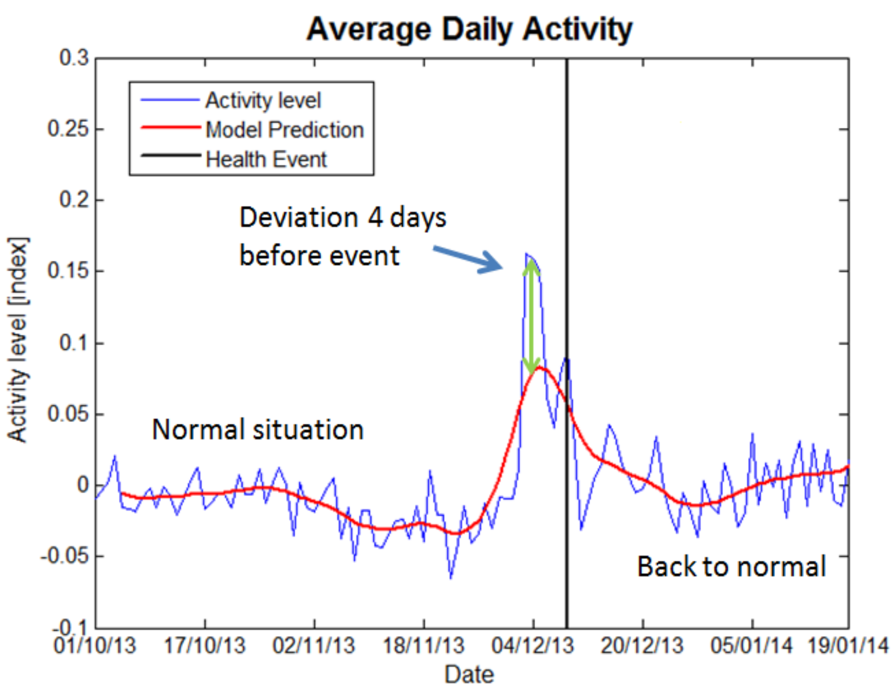


Figure 7: Detection of deviations from prediction of the average activity in relation to mastitis

Prediction of ketosis

Ketosis is also very common in dairy cows and can have negative impacts on production. This metabolic disease most often occurs in early lactation, when the energy demands for milk production exceed the energy intake by cows. Like SARA, the disease is typically under-reported due to non-specific clinical signs in especially the subclinical state. On one of the farms under study, 66 cows were closely followed from calving till 42 days later. A semi-quantitative milk test for measuring the ketone metabolite, β-hydroxybutyrate, was applied twice per week to detect ketosis (gold standard). Algorithm undertaken to predict ketosis involved principal component analysis followed by logistic regression modelling using half of the data available. Model evaluation was then performed using the other half of the data set. Unfortunately, this first attempt failed as the two different logistic models tested did not perform satisfactorily in predicting ketosis in fresh cows. We still need to investigate the new variables identified during the project (new spots of interest, indicators of the circadian rhythm) to better characterise the behaviour of cows under ketosis.

Coughing in calves and detection of respiratory diseases

In calves, respiratory disorders are frequent and can induce large economic losses. A total of 60 calves were monitored for 3 weeks in 3 separate barns. Clinical assessments were performed by a trained human. A health score, ranging from 0 to 12, was calculated based on nasal discharge, eye or ear discharge, cough, and rectal temperature. A calf is considered to be affected by a respiratory disorder if the score is 5 or more. At the same time, the sounds emitted by calves were recorded by the SoundTalks system (**Figure 8**). A calf cough detection algorithm was developed from these recordings (58% sensitivity, 99% specificity). The number of coughs detected by the algorithm corresponded with the number of calves with high respiratory scores. Moreover, periods with increased coughing detected from sounds, corresponded to the incidence of respiratory disorders. Such an early recognition of respiratory disorders allows earlier treatment intervention.

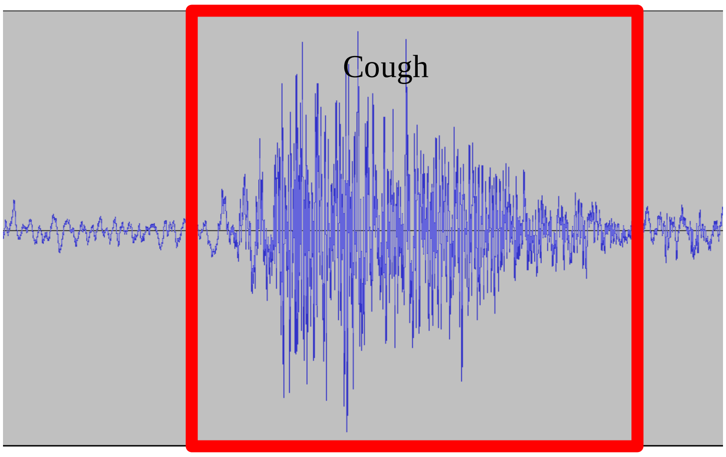


Figure 8: Detection of coughing by sound waves

Prediction of individual feed intake

Cow individual dry matter intake (DMI) is an important variable in dairy management, allowing assessing the efficiency of individual cows. A mathematical model developed before the project could be improved during the project. A total of 120 dairy cows were monitored for 117 days. The Model can be described as follows: the individual DMI is calculated as a function of the time spent by the cow near the through, production indicators (such as milk fat and protein content), physiological status (such as body weight changes, pregnancy status, days in milk), and activity measured by several sensors. Without PLF techniques, the model predicted 74% of the variability between cows whereas with PLF techniques tested during the project it predicts 94%. The model was tested with a total mixed ration and with a diet containing essentially forage.

Impact of feeding strategies

Some previous studies suggested qualifying feeding behavior into meals instead of just eating duration. We investigated whether this was possible with CowView in the INRA farm equipped also with BioControl troughs to measure precisely feeding behaviour (detection of when a cow visits a trough and the amount taken during each visit). The meals defined by the BioControl system were used as gold standard. Best result achieved was an overall test accuracy of 91.3 % and a correlation of 0.57 of total daily meal time between BioControl and CowView. Because of the variability in the modelling performance of the mixed distributions, it was decided not to include feeding behaviour qualified as meals in CowView. Instead, GEA decided that feeding behaviour will be presented in CowView as number and duration of short, medium and long feeding events.

As we know management actions can change animal behaviour, two feeding trials were conducted to create examples measuring changes in cow behaviour when changing feeding strategy using PLF technologies. In the first trial, the effect of an automatic mixed feeder serving 12 versus 6 times per day was investigated. The 12-time feeding out strategy resulted in shorter and more eating events and shorter total eating time per day. Furthermore, the many smaller servings resulted in more peaks in animal intensity at the feeding table during day and night and less residual feed left. The second feeding trial looked into the effect of pushing mixed feed to the cows by a robot feed pusher 3 versus 10 times per day. The 10 pushes resulted in longer feeding events and longer total feeding time compared with the 3 feed pushes. Furthermore, the cows had slightly better cow time budgets in terms of more time in cubicle and less time in alley ways with 10 feed pushes and the organisation of their activity during the days was closer to the spontaneous rhythm of activity of cows, with two peaks of activity, one in the morning and one in the evening, and a low activity at night.

BROILERS

Monitoring distribution and activity

A real-time algorithm was developed for the eYeNamic to compare the actually measured distribution of animals with a predicted value at that time of the day. When the real measured value was more than 25 % different from the predicted value an alarm was given to the farmer (**Figure 9**). The behaviour of the broilers is quantified continuously and by measuring the distribution of the birds, indications of blocked feeder lines and other problems are given. The PLF system shows that 95 % of all problems are detected from the behaviour of the birds (Kashiha, 2013). It used a single parameter: the variation in time of the birds' distribution of the available space. The PLF eYeNamic system (Fancom BV, the Netherlands) allows detecting most of the daily problems in broiler houses by continuously analysing the broilers' behaviour.

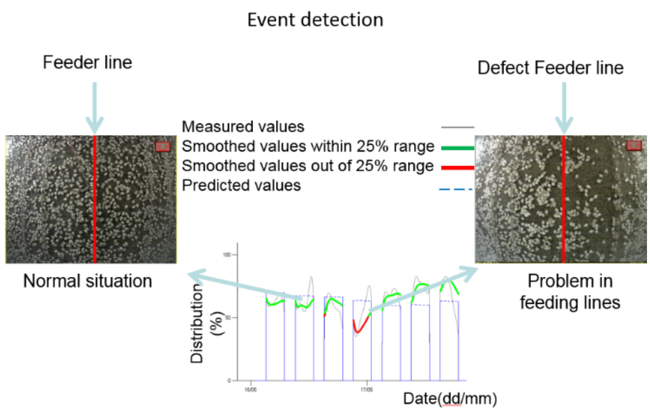


Figure 9: The early warning system and results from eYeNamic monitoring system

Activity-based emission monitoring

Analysis output might be used as starting point for the development of an algorithm capable of modelling dust concentration based on broiler activity. The consequences of those results would potentially allow the active management of aerosol concentration, without the need for expensive aerosol analysers, and to reduce aerosol emissions to the environment (**Figure 10**). (Demmers et al, draft).

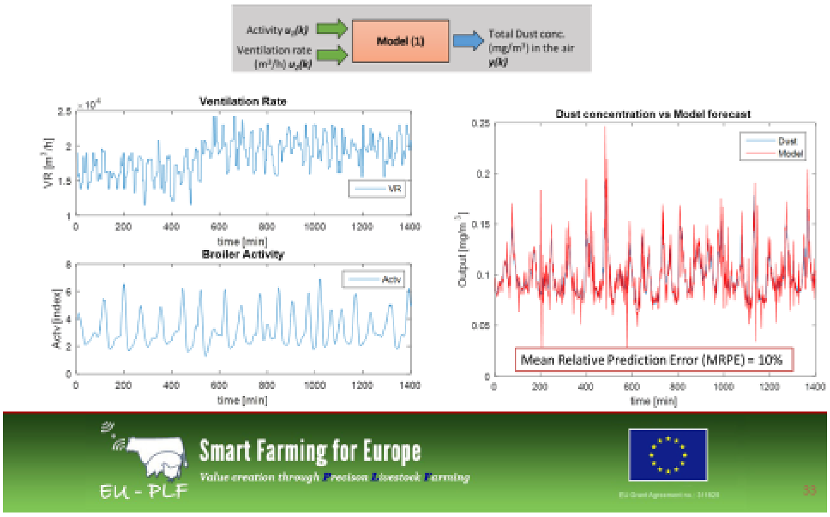


Figure 10: Activity-based emission monitoring from a broiler house

Sound-based growth monitoring

A further aspect of high importance in a broiler farm is the growth trend of the flock, since it is an important part of modern broiler production representing the efficiency and profitability of the processing plant. The average weight of the flock is generally evaluated either manually or automatically using samples of birds chosen at random within a poultry house. The manual measurement of the weight of a representative number of animals in a building is time and labour intensive, since buildings may hold up to 50k birds. Today, many farms use “step-on scales” placed on the floor of the poultry house to automatically collect the average weight of the birds in the flock. Even if the weighing system gives an accurate weight value each time a bird steps onto it, the weight is only representative for the birds that access the automated weighing system and certainly not representative for all the birds in the flock. The accuracy of automated weighing is limited due to (a) the reluctance of heavy birds to visit the weighing scale (which requires the bird to climb up onto the scale) at the end of the production period and (b) the walking ability of fast-growing broilers that decrease with age, reducing their mobility and willingness to move. Moreover, sick, lame and very heavy birds reduce their locomotor activity, and extend the time periods spent in resting and lying behaviour. Therefore, while current automatic weighing systems reduce time wasted by the farmer for manual weighing of birds, they may fail to continuously follow the growth trend of the whole flock, whilst simultaneously not estimating the weight of sick, lame and very heavy birds that are reluctant to move and to jump onto the automated scale. During the EU-PLF project, the use of sound recordings collected with the commercially available SoundTalks® monitoring system, allowed to find a clear and inversely proportional relation between Peak Frequency of the sounds emitted by broilers and their weight.

A clear relation between weight and vocalization frequency was found, leading to a study focused on the prediction of the growth trend according to changes in peak frequency of the sounds emitted by the broilers (**Figure 11**).The results indicate that modelling the growth trend as a function of the peak frequency of the sounds emitted at farm level was proven to be reasonably accurate (Fontana et al, 2015).

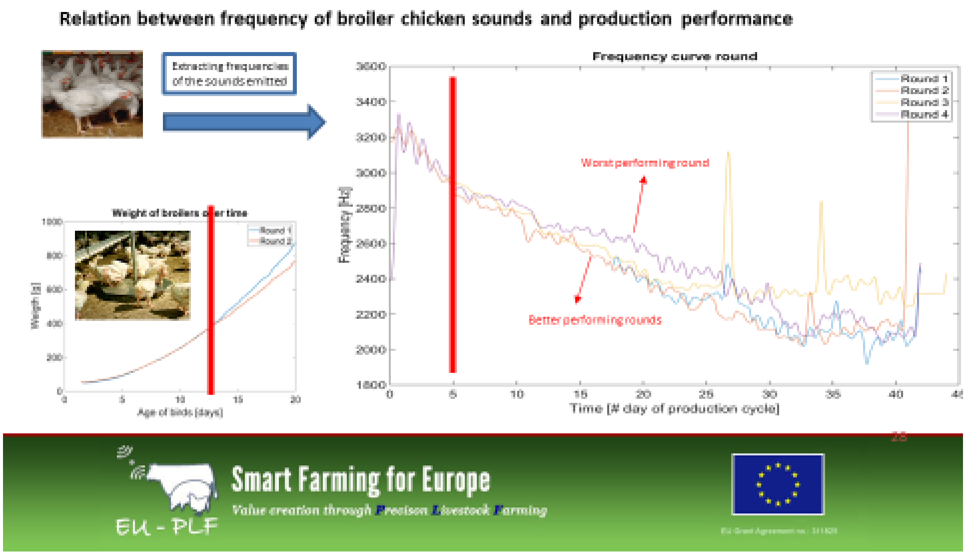


Figure 11: Sound-based growth monitoring in a broiler house

Out-of-comfort monitoring

Another challenge for the broiler farmers is to manage the house to stay in the optimal thermal comfort zone for the broilers. Broiler performance is heavily conditioned by environmental parameters such as temperature, relative humidity, air and litter quality and ventilation speed. Broilers are reared under different temperature and humidity ranges according to their age and a tightly controlled environment improves animal health, well-being, and production efficiency. To this end, temperature, relative humidity and ventilation rate are constantly controlled and managed by automated systems. Several investigators have reported that broilers can tolerate a wide range of relative humidity and still perform efficiently, but fast changes in relative humidity can rapidly and negatively influence litter conditions, that have been associated with lowered carcass quality and increased leg and foot abnormalities. Among leg disorders, footpad dermatitis is a significant welfare concern to the broiler chicken farming industry. Footpad dermatitis is characterised by skin lesions that can start from a discoloration of the skin finally turning into epidermal necrosis. These lesions may become a gateway for bacterial infections thereby affecting the bird’s health and the walking ability of the birds, with the reduction of the animals welfare. Indeed, lame birds may also find difficult to reach food and water. Since the animal health strongly depends on good welfare, during the last years many progresses has been made in developing new indices and procedures to assess animal's health and welfare status. But, so far, the most commonly used outcome measure of living birds on a large scale is to observe individual birds walking and score them using a ranked scale. The Welfare Quality® protocol for boilers requires a lot of trained manpower/labour and it is time-consuming and could potentially create biosecurity risks moving assessors between farms. In order to develop an automated prediction system to detect footpad dermatitis and lameness, data from the climate control system (FarmManager, Fancom) and data from manual welfare scoring where merged to find a correlation between climate and leg problems (**Figure 12**). The analysis shows that footpad dermatitis and lameness were strictly linked to the environmental conditions and that can be controlled with the automated system (Tullo et al., 2015).

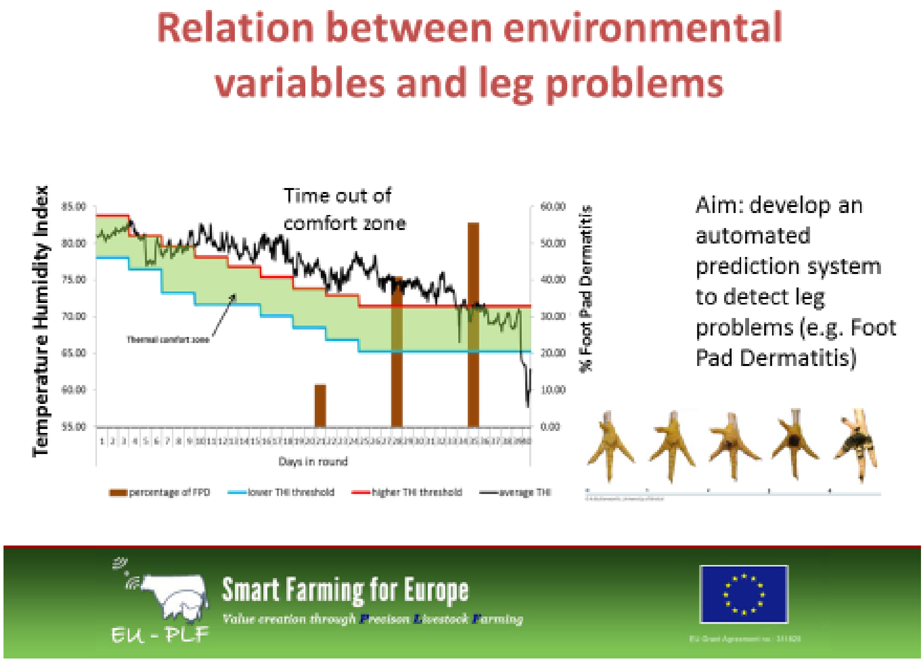


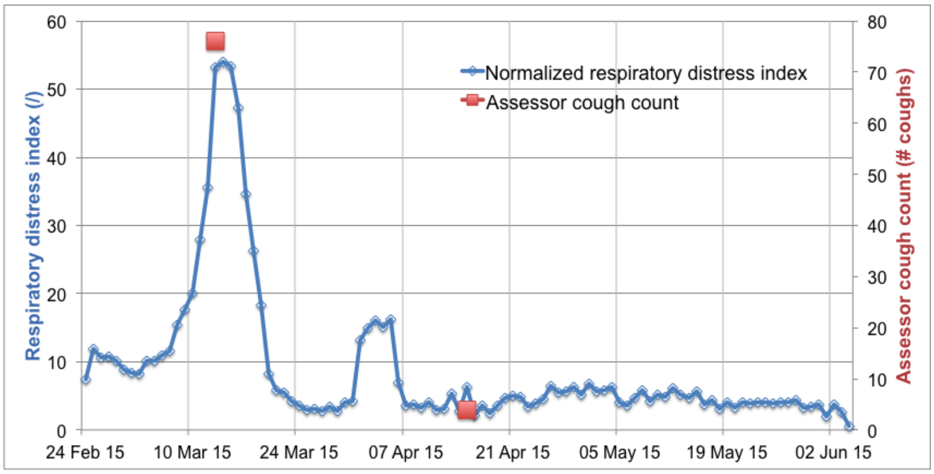
Figure 12: Relationship between time spent out of thermal comfort and leg problems

<u>PIGS</u>

Pig cough monitoring

During EU-PLF the pig cough monitoring algorithms were made more robust for commercial conditions. Results were compared to diagnosis performed by veterinarians and this work demonstrated how the tool gives earlier warnings (up to 2 weeks earlier) compared to a situation where the farmer and veterinarian rely on their own routine observations. It was also demonstrated that the tool works for the early detection of animal responses due to technical issues (ventilation problems) and health issues in a wide range of different conditions in commercial European pig houses (Berckmans et al, 2015). In general the findings of the human assessor are in good correlation with the respiratory distress index, as a high number of coughs were counted on several occasions in several pig houses as shown in published material (**Figure 13**). It is clear that the continuous automated measurement of respiratory distress gives a more detailed picture of the complex respiratory situation in the pig house. The clear increase in the respiratory distress index from March 8th-14th corresponds very well with the high number of coughs (76) counted by the assessor on March 13th. Only on March 12th, i.e. about 4 days later than the increase in the respiratory distress index, the farmer first noticed an increased level of cough during his routine check of the compartment. In combination with diagnostics and the knowledge from farmer and veterinarian, the respiratory distress monitor proves to be a tool with high added value and economic impact.

Infection case



Case in the Netherlands

Figure 13: shows the evolution of the respiratory distress in function of time, measured on a farm in the Netherlands. On February 24th 2015, 72 piglets of 10 weeks old were placed in the compartment.

Pig water consumption monitoring

Another aspect related to housing management was the drinking behaviour of pigs. It was studied using camera-based technology, the eYeNamic^{TM} system from Fancom. The system was installed above the pen to estimate the water use of fattening pigs automatically. Automated image processing and transfer function modelling allowed the estimation of half-hourly water usage with high accuracy (92%). Through image processing techniques, the duration of a pig staying at the drink nipple was calculated. Then, a Transfer Function model was developed to evaluate the water consumption as function of the duration of the visit to the drinker. Estimating water use of pigs can help us to understand how drinking behaviour of pigs is related to their water use. Moreover, this offers many potential applications to improve animal husbandry management.

Pig activity and space occupation monitoring

In the meantime, the same system from Fancom (eYeNamic^{TM}) was used to identify and follow-up an activity pattern in a pig group during the growing period. The system interpreted the collected images, calculating the activity and the distribution of the pigs in the image. Animal shapes were automatically segmented from the background floor area. Further image analysis translated the acquired images into indices of distribution and activity. Activity was calculated from the subtraction of two consecutive segmented images. The distribution of the pigs was based on the segmentation of the pig pixels in the image. These indices are a measure of the animals' position and movement, and can help in monitoring and studying basic animal behaviour. From the activity sampling, the percentage of time at resting and in high activity were calculated when all data were aggregated. These estimations showed the potential of PLF data in the field.

4.5 WP 4: Definition of value creation

Many PLF technologies have been developed in recent years but the uptake of most of these technologies on commercial farms has been slow. A number of reasons contribute to this slow uptake by farmers:

- the lack of conversion of PLF data into useful, easily understandable information for quick decision-making
- the need for significant investment in PLF technologies with an un-demonstrated farmer return of investment

Insight into the impact of PLF on farm economics is, therefore, of great importance. PLF is likely to become more successful when information on the economic value-add is available and especially if such value-add can be expressed in monetary terms.

4.5.1 Work carried out during WP 4

One of the objectives of the project was to study the social and economic value for different PLF applications on-farm and in the supply chain. The specific objectives of the WP4 are:

- Analyse socio-economic data related to value creation from farm measurements in WP2
- Analyse in-depth value creation potential of the food supply chain (feed-animal-food)
- Find stakeholder-dependent social, and economic incentives for the adoption of PLF

The socio-economic impact of PLF is not well understood. To be able to study these aspects, Key Performance Indicators (KPI) for the socio-economic effects were studied. Interactive sessions were conducted where the farmers, retailers, and feed providers were exposed to several "trending topics" like environmental sustainability, animal welfare including tail cutting, use of antibiotics etc. From literature research and these discussions, a list of important socio-economic indicators was developed. The initial list was then refined by incorporating insights and feedback from workshops in the Dutch-Flanders area, interviews with integrators in Catalonia and results of the web-based questionnaire. Based on the combined results, the five most important social key indicators of PLF are:

1. Labour conditions (physical, dust, environment, light…)
2. Number of labour hours
3. Pride/motivation to talk about and show animal and production facilities
4. Availability of advisory systems
5. Successor for farm business to continue the farm

Other indicators like job satisfaction, risk awareness and social recognition were also found important.

The most important economic key indicators of PLF came out to be:

1. Feed conversion
2. Growth
3. Health costs
4. Delivery weight
5. Energy costs

Uniformity, mortality, farm income, noble parts/units and control of waste production and manure are also important.

The net economic benefit of PLF technology when applied on-farm is one of the key characteristics that determines the potential value of a PLF technology.

To calculate the effect of PLF products and services an appropriate a-priori methodology is required how to measure added value. After a number of conversations with farmers and based on the results of the ALL-SMART-PIGS project, the benefits of PLF technologies were found to fall into three categories: Tangible, semi-tangible and intangible benefits. The selected indicators mentioned previously, were used to develop tools to assess the economic value of PLF technologies with the mentioned levels of expression and to evaluate the preferences for social or economic benefits of PLF technologies (task 4.2).

Value Creation Tool (VCT) assesses the potential economic benefit of implementing PLF technologies on dairy/fattening pig/broiler farms. The VCT is a generic and straightforward tool using technical parameters at the farm level, and data on investment, prices, and costs. Four baseline scenarios were considered per animal group, representing four default situations without PLF implementation.

The baseline scenarios were developed using two economic parameters (labour efficiency and capital intensity) (**Figure 14**). For each scenario, a region/country was selected in which farms were expected to meet the criteria. The VCT then computes two outcome parameters: labour income and net farm income. Values of input parameters that are affected when PLF is implemented can be changed manually, and a new labour income and net farm income are calculated. The difference between the default situation and the PLF situation is the economic effect of implementing PLF on-farm. This VCT was considered the right tool for tangible effects, so for PLF technologies that can be linked to farm management areas and/or actions.

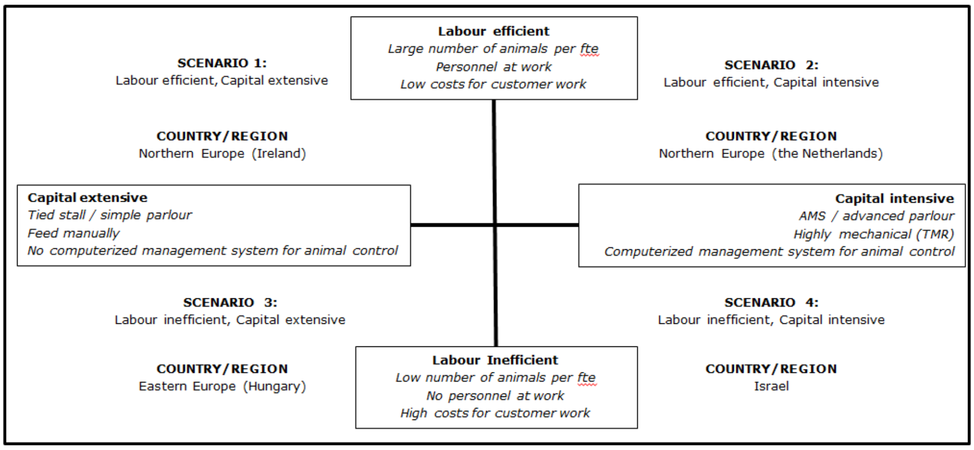


Figure 14: Baseline scenarios for dairy farms based on labour efficiency and capital intensity

Break-even tool (BET) developed to assess the semi-tangible effects. For PLF technologies that are expected to have an economic effect, but where the impact on farm management areas are less clear, a Break-even tool (BET) is designed. This tool helps to estimate how much change in one input parameter used in the VCT would be required to break-even with the net farm income after investing in the PLF technology. To use this tool, prior knowledge on the costs of investment in PLF technology is required. Input parameters that could be changed are those parameters of most interest for farmers (e.g., labour hours, milk yield for dairy farms, or feed conversion rate for fattening pig farms or broiler farms).

Adaptive conjoint analysis (ACA) designed to provide insight to the preference of farmers for social or economic benefits of PLF technology – the intangible effects. In assessing the preferences with this tool, six attributes with 2 or more levels have been considered. These attributes were based on the social and economic key indicators prioritized earlier in task 4.1. Those attributes are labour condition, workload, farmer's image, farm performance, energy requirements and animal health.

The Value Creation Group has also started to look beyond the farm level and study value creation in the supply chain. The aim is to find out whether the investment in and the use of PLF technology has indeed a positive impact on the production results and whether the value can be created at farm level and along the production chain. The value creation potential of PLF, both on-farm and in-chain are studied in a holistic analysis. A business model is proposed and the possibility of implementation and sustainability of PLF with this model were studied.

As a first step, the potential values and economic benefits (of PLF) for exchanging information along the chain and among all stakeholders were evaluated.

Parameters affecting cost-effectiveness, sustainability, fair and ethical trade -which were identified as contributors to the “triple bottom line” vision concept- were explored and the feasibility of having a “Responsibility Index” (RI) as an umbrella for other existing labels was studied (**Figure 15**).

Triple bottom line (or otherwise noted as TBL or 3BL or 3P) is a framework that goes beyond the traditional measures of profit, return on investment and shareholder value to include environmental

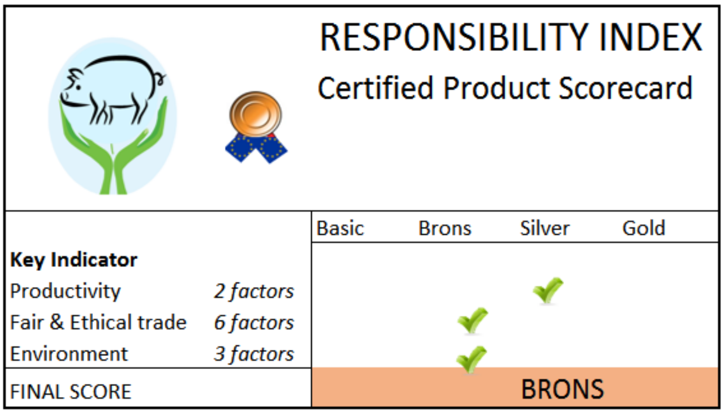


Figure 15: Visualisation of the Responsibility Index which could be displayed on products

and social dimensions and thus can be an important tool to support sustainability goals. The Responsibility Index which could act as an umbrella for the existing labels designed and used to approach the stakeholders and evaluate their feedbacks.

This index is based on the information collected by PLF from farms. Partly it is based on static information (e.g. economic profitability) and partly on data directly measured by PLF (such as health issues). Ideally, the Responsibility Index would be used as a benchmarking tool for sourcing e.g. by supermarkets. The Responsibility Index was conceptualised and presented to stakeholders in the supply chain. Feedback was collected via questionnaires, personal interviews, meetings and workshops and later analysed.

The results of the analysis demonstrated that feed companies were neutral about the RI and believed that the index will provide no immediate benefit. Farmers showed a positive attitude about benchmarking themselves with such an index, most likely because farmers feel that their good efforts are not recognised enough by their clients. Retailers were generally in favour of having one umbrella label covering all concerns at once. However, they believed that such a label should be simple and easy to understand. While the RI would be useful for benchmarking, it was felt to be too complicated for consumer communication.

The most important key indicators from the point of view of the stakeholders were "number of animals treated with medication" and "animal health issues". It should also be mentioned that reaching out to retailers was very difficult and that further discussions with this type of stakeholder are necessary.

We conclude from this research that the creation of summary information in the form of a Responsibility Index (or FarmScore, as it was called in the EU-funded project BrightAnimal) is seen as positive, but that it is currently not possible to quantify the economic impact of the creation of such an index. However, summary data is not the only candidate for in-chain value creation. The Value Creation Group continued with testing the value of detailed data ("big data") to the different supply chain partners of farmers. Data captured on farm can be valuable to farm input suppliers to gauge the quality of their products, to integrators for better farm monitoring and to clients for improved quality management and better risk management. **Table 4** summarises the value proposition for each stakeholder.

Table 4: The value proposition generated by flow of information along the chain

Breeders	Feed providers	Integrators	Farmers	Food companies/Retail
Efficiency of the breed material	Impact of feed composition on the animal indicator, performance control	Farm KPIs for quality management	Incidence management, predictability of results	Brand risk management

As can be seen above, in a distributed PLF business model the beneficiary of PLF is not just the farmer but also other stakeholders of the chain (**Figure 16**). As an example, for feed providers and nutrition companies, growth monitoring, health status tracking, feed and water consumption records will provide a near real-time feed/nutrition performance feedback. This allows feed regimes improvement and optimization to reduce growth variations and non-uniformity and increase disease resistance. Feed formulation can be optimised based on real commercial clients rather than testing on a small number of research farms. In addition, feed companies can create better growth curves and use them in their marketing to farmers. Real data from farm can also be used to defend feed companies against claims from farmers about non-optimal growth.

If feed is adjusted during the fattening round according to real growth, this will greatly benefit the farmer. More predictable growth due to adjusted feed in turn will improve the management of abattoirs. Due to greater uniformity, farmers will receive better prices and abattoirs can increase their productivity. The proposed business model foresees that PLF hardware and software would be provided by service providers. These service providers will manage the technology, its installation

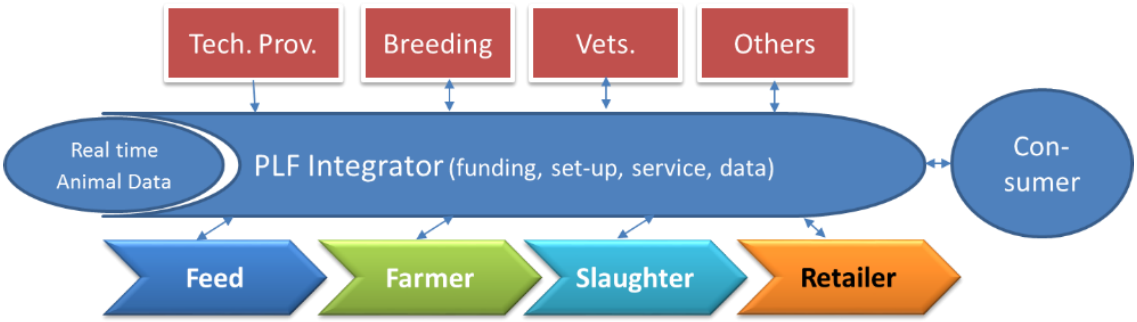


Figure 16: The PLF Business Model, Cost of PLF investment & operation shared along the value creation chain by payment for

and maintenance and in addition provide consultancy and reporting; stakeholders – including farmers - would subscribe to “PLF as a service” to get access to the data (and its analysis).

The feasibility of implementing PLF based on the mentioned business model and estimating whether there is enough interest in the supply chain to sustain such an online information service/platform were studied in task 4.4.

Using a choice experiment method, a reasonable offering for different supply chain actors was designed and presented to stakeholders, with the view on obtaining feedback on the likelihood of success of offering and their economic evaluation. The choice-sets, hereinafter called “products”, were mock-ups for selected stakeholders of pig and poultry chain (farmers, feed providers, breeders, and integrators) with different access levels and features.

The stakeholders’ comments and feedbacks on Willingness To Accept (WTA) and Willingness To Pay (WTP) were collected through personal interviews, workshops, questionnaires and by assisting trade fairs.

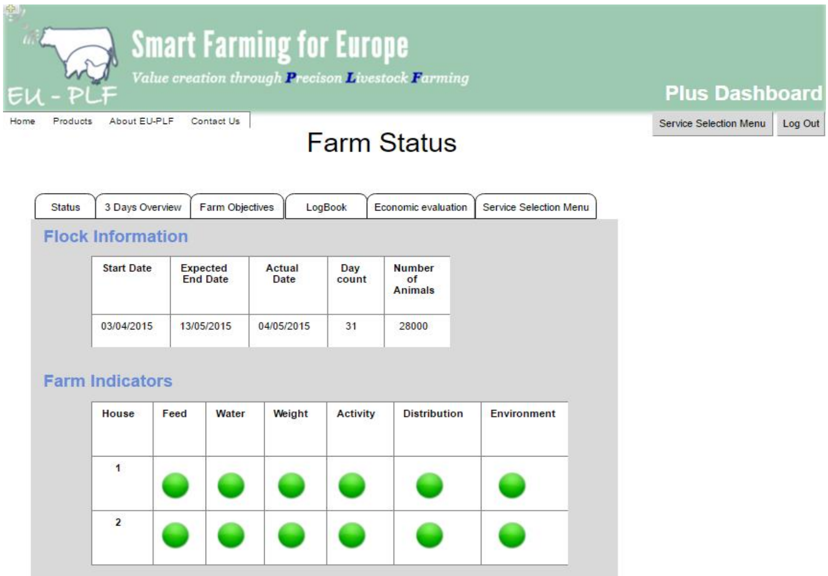


Figure 17: A view of the main dashboard for poultry farms

The analysis of the results shows that the willingness to pay of farmers for PLF as a service is generally very low. That could be due to various reasons such as lack of consideration of cost scaling of PLF technologies or the value of information is not tangible enough for farmers. Other stakeholders, especially feed providers, show interest and are willing to pay for receiving information from the farm they supply. According to the analysis, as summarised in **Figure 17**, full-scale implementation of PLF in pig farms seems very difficult because of high ROI for the service provider. Several solutions to address this problem could be envisages, such as:

- partial implementation of PLF on a sample basis (assuming production is approximately homogeneous over compartments of the same batch)
- co-funding by farmers, i.e. a model where farmers contribute to the investment cost- this, however, would increase the time for a return on investment for farmers
- changing from the current farming model with small groups of pigs to larger groups (e.g. group sizes of a hundred pigs or more, thereby reducing the investment cost by a factor of 5)

The latter solution is likely the best solution for new farms where larger group sizes will also reduce the investment cost of buildings.

The situation is different for poultry. Here, full implementation of PLF as a service on this chain seems feasible. This is not only because the implementation of technology is much more accepted in the poultry than the pig sector (and therefore WTP/WTA higher), but also because poultry farms already have larger groups sizes and are more apt for technology installation (**Figure 18**). This reduces drastically the investment costs for implementing PLF. As a result of a large number of interviews with stakeholders in the EU-PLF project it became clear that Precision Livestock Farming has its particular audience and it is not appealing to all type of farmers. Partly, this is due to the innovative nature of PLF and can therefore be addressed through dissemination, awareness campaigns, training and education. A major breakthrough can be expected when the first adopters reap consistent competitive benefits compared to their peers. This can be expected to happen within the next 5-10 years.

Key to a successful adoption of "PLF as a service" will be a clear and sound governance model. It is the view of the project that data should be owned by farmers, but ownership over aggregate data needs to be clarified. The best possible solution to avoid governance issues is for the data to be owned by farmer associations. Given that the data then would be owned indirectly by the farmers themselves, this would clearly address one of the main concerns farmers have voiced in the interviews: that they are being robbed of their data.

Fattening pig farm of 2400 places, 3 rounds/year		Broiler farm of 30,000 places, 7 rounds/year	
Actor	WTP (approx.) per animal	Actor	WTP (approx.) per animal
Supply chain	1.2 EUR	Supply chain	4.1 Cent
Farmer	0.32-1.2 EUR	Farmer	1-4.1 Cent
ROI	4-11 years	ROI	0.4-1.6 years

Figure 18: Summary of the WTP/WTA analysis of PLF as a service

Analyse data collected on site and derive models for value creation

In general, there are three methods to evaluate the cost effectiveness of interventions. The first methods is an ex-ante analysis of the cost-effectiveness. Because the intervention has not yet been implemented, there are no data to work on, except, maybe, experimental data. Therefore, simulation modelling is used to predict the cost-effectiveness. The simulation models can vary in preciseness and robustness, from straightforward calculation models (for instance based on Partial budgeting), to complex bio-economic simulation models. In any case, input values have to be estimated based upon knowledge from experiments, databases, scientific literature and experimental results.

The second group of cost-effectiveness analyses are ex-post analyses. These can have two forms: systematic evaluation and case studies. A case study is typically about one farm, where there is experience with the intervention. The farmer can report changes in performance of the farm, or these changes can be retrieved from farm records. I a more systematic approach, data about the change in farm performance are needed for a large enough number of farms to determine an accurate estimation of the effects. These analyses could be based upon technical farm performance, normatively transformed into economic performance or can be based on economic (accounting) data.

With EU PLF we have worked with ex-ante calculations as well as with ex-post case studies.

Ex-ante calculations

During a EU-PLF workshop organized in Unna in April 2014, it became clear that it was hard to retrieve information about the (range of) impact of PLF technologies on input parameters in the absence of a clear farm description on which the PLF technology would be implemented. To overcome this problem, for each animal group, four baseline scenarios for the Value Creation Tools were developed. These baseline scenarios are developed such that a wide range of different farm situations were covered. Two economically-based criteria were used to define these baseline scenarios: labour efficiency and capital intensity. For each baseline scenario, a region and country was selected in which farms were expected to meet the criteria. **Figure 19** and **20** graphically demonstrate the baseline scenarios for dairy farms and for fattening pig or broiler farms, respectively. For each baseline scenario, values for the input parameters used in the Value Creation Tools were identified based on expert knowledge, or assessed from literature or national agricultural databases. Each baseline scenario, thus, represent a situation within the Value Creation Tools in which PLF technology is not implemented.

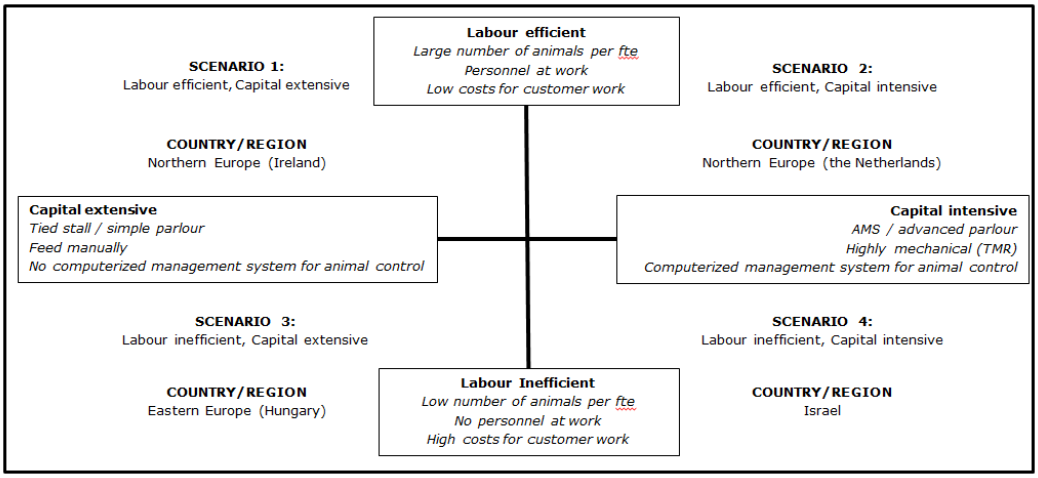


Figure 19: Baseline scenarios for dairy farms based on labour efficiency and capital intensity

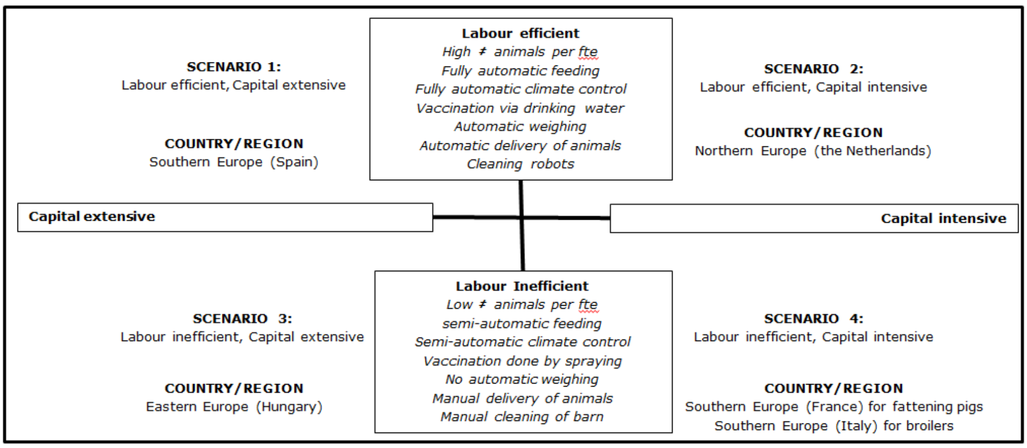


Figure 20: Baseline scenarios for fattening pig farms or broiler farms based on labour efficiency and capital intensity

Using the Value Creation Tool: the example of automated heat detection on dairy farms

As baseline scenario, the scenario of a labour efficient and capital extensive dairy farm is chosen (Scenario 2, **Figure 19**). Farms that meet the described criteria of this scenario can be found in, e.g., the Netherlands. Therefore, the Dutch national database (LEI, 2014) and literature are used to determine values for the input parameters used in the Value Creation Tool for dairy farms. These values are listed in **Table 5** and define a situation in which no PLF technology is implemented. Using these values and the aforementioned formulas (formula 1 through 12), the Value Creation Tool estimates NFI at €11,933 and LI at €49,373.

Table 5: Input parameters and their units that are used to estimate the economic impact of PLF technologies on dairy farms. The values presented are for a labour and capital intensive dairy farm (LEI, 2014, unless otherwise stated) without PLF technology (no PLF) and for the same farm when automated heat detection (PLF) is implemented. Values for parameters that change due to the implementation of PLF are coloured grey

Input Parameters	Unit	No PLF	PLF
Technical parameters			
Labour	FTE	1	1
Labour hours	Hours/year	2,080	2,080
Farm size	Dairy cows	80	80
Replacement heifers	% of dairy cows	38	30[c]
Mortality Replacement heifers	% of replacement heifers	10	10
Land	Ha	49	49
Milk production	Kg milk/cow/year	8,100	8,222[c]
Buildings, machinery, and equipment			
Value of Land	€/ha	27,000	27,000
Interest rate Land	%	2	2
Nominal interest rate	%	5	5
Replacement value of buildings [1]	€[b]	800,000	800,000
Depreciation buildings	% of total investment	4	4
Maintenance buildings	% of total investment	1.5	1.5
Replacement value machinery and equipment	€	126,000	126,000
Depreciation machinery and equipment	% of total investment	10	10
Maintenance machinery and equipment	% of total investment	5	5
Replacement value PLF	€	-	10,000
Depreciation PLF	% of total investment	-	10
Maintenance PLF	% of total investment	-	1
Prices			
Dairy cow	€/dairy cow	1,200	1,200
Heifer (1-2 years)	€/heifer	835	835
Calf	€/calf[b]	100	100
Milk	€/kg milk	0.39	0.39
Labour	€/hour[a]	18	18
Other Revenues			
Livestock revenues	€/dairy cow	259	259
Miscellaneous revenues	€/dairy cow	166	166
Other Costs			
Concentrates, milk products, minerals	€/dairy cow	680	690[c]
Roughage	€/dairy cow	121	121

Land lease	€/dairy cow	0	0
Fertilizer and pesticides	€/ha	87	87
Customer work	€/dairy cow[b]	200	200
Health care (preventive)	€/dairy cow[b]	50	50
Health care (curative)	€/dairy cow[b]	150	150
Artificial insemination and Breeding	€/dairy cow	80[b]	70[c]
Miscellaneous costs	€/dairy cow[b]	200	200
Other variable costs for PLF	€/dairy cow	-	-

[1]incl. milking parlour; [a]Huijps *et al.*, 2008; [b]Expert knowledge; [d] based on Mohd Nor *et al.*, 2012

The alternative situation within the Value Creation Tool describes the same labour efficient and capital extensive farm but with implementation of automated heat detection (PLF; Table 5). The investment costs were estimated at €10,000 with a depreciation period of 10 years and annual maintenance costs of 1% of the investment. Using these new values for input parameters, the Value Creation Tool estimates an NFI of €14,662 and an LI of €52,102 for the PLF situation. In other words, investing in automated heat detection has an estimated positive economic impact of €2,729 per annum for this labour efficient and capital intensive dairy farm.

Using the Baseline Scenarios: the example of automatic pig sorter on fattening pig farms

The different baseline scenarios can also be used to identify in which scenario PLF technologies are expected to have the biggest economic benefit or impact. On fattening pig farms, pigs are delivered to the slaughter house when they have reached a certain live-weight. In some countries, however, the price per delivered pig is reduced if there are too many pigs outside the expected pre-defined live-weight range. Automatic weighing and sorting of fattening pigs can help farmers to preselect pigs, to better estimate when the majority of the pigs are in the right live-weight range, and to adjust feed if necessary. Moreover, delivery costs and feeding costs can reduce as a result of this automatic pig sorter. All four baseline scenarios for fattening pig farms (**Figure 20**) are used to assess the potential economic benefit. For each baseline scenario, values for input parameters are found and these scenarios assume to represent farms without automatic pig sorter. Those input parameters affected by the pig sorter are adapted to estimate the economic situation for a farm with this PLF technology. The difference in NFI and LI between these two situations can be calculated with the Value Creation Tool for each baseline scenario. **Figure 21** summarizes results for differences in LI. Other baseline scenarios also demonstrate to have a positive economic effect on LI, but to a lesser extent. Within each of the analysed baseline scenarios, the automatic pig sorter had the biggest effect on feed costs and delivery costs. The economic benefit for the labour efficient and capital intensive fattening pig farm is much larger, particularly because the automatic pig sorter has a large impact on the price per delivered fattening pig by reducing the reduction of the delivery price by the slaughter house.

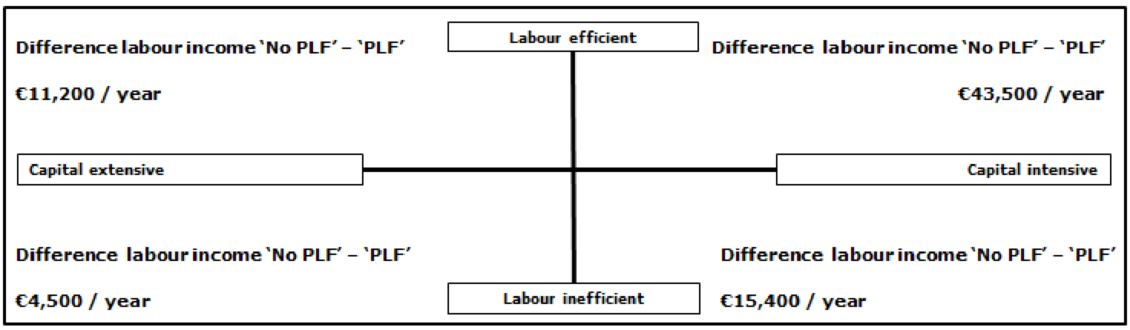


Figure 21: Difference in labour income between farms without PLF (No PLF) and those with an automatic pig sorter (PLF) for four Baseline Scenarios for fattening pig farms. Differences are calculated using the Value Creation Tool for fattening pig farms, for all four Baseline Scenarios (see Figure 19).

4.6 WP 5: Innovation through high-tech SMEs

In this WP high-tech SMEs and their technology will be identified and spin-off companies created and trained to market/commercialise developed PLF technology. This was realised by the following specific objectives.

1. Identification of valorisation of additional promising PLF technologies in SMEs and research labs
2. Coaching teams in valorisation of existing technology in the field of PLF through spin-off creation
3. Demonstration of valuable PLF application through developed prototypes
4. Spin-off creation

4.6.1 Work carried out during WP 5

The coaching process was applied to 30+ teams (for confidentiality reasons, the names of the teams cannot be made public). 4 prototype developments were coached in the field of PLF.
Different new technologies were adopted, ranging from camera based inspection systems, over position tracking solutions, dose administration and sensor fusion solutions. Many technologies were mechatronics technologies, requiring a profound understanding of electronics, mechanics, optics, robotics, and ICT.

The coaching activities resulted in the creation of 4 new high-tech companies, active in the field of PLF:

1. Ymaging, Barcelona, with their PigWei system for measuring the weight of pigs
2. Bainisha, Antwerp, with a motion detection sensor for different applications
3. Connecterra, Amsterdam, with an estrus detection solution
4. Cowmatix, Milan, with an infrared hoof monitoring system

The technologies developed during coaching and prototyping are listed below.

1. **Ymaging**

A PigWei system is developed, based on three technologies:

1. Optical sensor fusion and calibration
2. Mathematical pig model
3. Wireless communication and remote computing

Using these three technologies, Ymaging was able to build a prototype PigWei system, that fulfilled the specifications generated by potential customers.
The biggest challenge was in the realisation of the accuracy specification. A large number of measurements was used to fine tune the mathematical model. New optical calibration techniques were used to realise the high accuracy specification.

2. Bainisha

A flexible stretch sensor technology platform was developed, using a capacitive elastomer.
The Bainisha technology platform is based on these different technologies:

1. Sensor fusion between stretch sensor and inertial sensors
2. Wireless communication and networking to enable multiple sensors
3. Sensor calibration in a defined coordinate system
4. Battery management and data processing
5. Interfacing of the stretch sensor onto skin
6. Ruggedized and waterproof design

For the applications in PLF, a waterproof and ruggedized sensor concept was necessary. Specifications were developed not only for animal use, but also for use on humans. Applications are in lameness detection, and detection of contractions.

3. Connecterra

Connecterra developed a sensor platform for e.g. estrus detection.
Connecterra's end-to-end solution consists of a wearable device, which monitors the herd in real-time and transmits the data to a cloud platform for analysis and prediction of behavioural patterns. This allows farmers to free up labour time, improve milk production per animal and save a significant amount of money by optimising their breeding cycles.

Technologies developed by Connecterra are:

1. Sensor platform for motion detection
2. Wireless data transmission
3. Cloud platform

4. CowMatix

CowMatix developed an infrared hoof monitoring system. An infrared camera is combined with an RGB camera to overlay images, and to detect infections in an early phase.

The CowMatix technology is based on the following elements:

1. Optical camera's for hoof localisation and temperature measurement
2. Mathematical model and database
3. Remote analysis and warning solutions

Early detection of hoof problems is a key element for farmers to keep their cows healthy. This unique selling proposition is supported by the described technology platform.

Socio-economic impact of the new PLF companies

These four new high-tech companies already generated 20+ new jobs. These companies are growing, and active at a European scale. It is expected that some of these companies will take up a leader role in their field. Through the creation of these companies, sustainable EU PLF valorisation is realised. If each new job generates +/- 30Keuro for society, then about 200 manyear jobs are necessary to realise a break even for this EU PLF project. This means that if these 4 companies can maintain 20 jobs for the next 10 years, a break-even situation is reached. It is expected that these companies will grow at a rate of 30% per year. This implies that after five years, the number of jobs is increased to +/- 100, and a break even situation for the EU is reached.

4.7 WP 6: Creation of the Blueprint

The context for the successful usage of the PLF technology and its applicability is described within WP 6 in form of a blueprint. Each Work Package has contributed to the **blueprint** being the most **important project result**. The specific work package objectives were:

1. Definition of blueprint format and protocol.
2. Collection and review of information delivered by other WPs to be used for blueprint
3. Blueprint creation

4.7.1 Work carried out during WP 6

The target groups for the EU-PLF blueprint are farmers and the service industry. Although we thought at the start of the project to create a manual, we have in the meeting of 11/12/2014 decided to implement the information in a website. The EU-PLF blueprint and the e-course will complement each other and be placed under a common umbrella. They will have many links between each other. People going through the blueprint may get more in depth knowledge from the e-course (educational material). People studying the e-course may have more practical visions from the blueprint (hands-on material). When consulting the EU-PLF blueprint participants will first be asked to which target group they belong and what their main focus is. On the basis of the information provided by the participant (s)he will be suggested a pathway along the various units of the blueprint and the e-course (e-learning course is available to the project partners for feedback). At any time participants can easily switch from blueprint to e-learning and vice versa.

E-learning	**Blueprint**

• An Introduction to PLF
• Basics on animal science and livestock farming systems
• Principles and examples of PLF and data analysis
• Added value from PLF
• Case study
• CONCLUSION: present and future trends of operational PLF
	• An Introduction to PLF
	• PLF technology
	  o Broilers
	    ▪ eYeNamic
	      • Technology
	      • Product
	      • Value
	  o Pigs
	    ▪ eYeNamic
	      • Technology
	      • Product
	      • Value
	    ▪ Respiratory Distress
	      • Technology
	      • Product
	      • Value
	  o Cows
	    ▪ CowView

	• Technology • Product • Value • Business Models • Problems & Solutions

Figure 22: Structure of the EU-PLF Blueprint and e-course

Validating, improving and finalising the blueprint

The aim is for the blueprint to be used as a reference tool offering pragmatic guidance on how Precision Livestock Farming (PLF) systems can be implemented at farm level in order to create value for the farmer and other stakeholders. It will analyse how Precision Livestock Farming technologies can create value at farm level by improving animal welfare, health, environmental load and productivity, extensive field tests are carried out by scientific and industrial partners in collaboration with high tech Small and Middle-size Enterprises. Moreover 20 farmers, spread over Europe, have used and experienced the technology and actively given feedback to help us develop this Blueprint. Highly experienced European teams from different disciplines with a proven track record in animal and Precision Livestock Farming-related fields - animal scientists, veterinarians, ethologists, bio-engineers, engineers, social scientists and economists, leading industrial market players in the livestock industry and high tech Small and Middle-sized Enterprises – have joined a consortium together with 20 farmers to deliver the EU-PLF Blueprint, a useful practical guide. The blueprint is made for all stakeholders related to PLF, representatives of the stakeholders (mainly stockpersons and related industry).

Development of the blueprint was done in collaboration with Agrocampus-Ouest in France. The URL of the e-course and blueprint website is: http://plf.agrocampus-ouest.fr. The blueprint farmers and industry professionals must logon to the the e-course website. There you can request a login credentials. Upon entering the blueprint portal the reader is first introduced to the structure of the blueprint, which is shown in Figure 23.

Figure 23: A screen shot of the blueprint structure

We agreed to realise the structure presented in **Figure 22** so the introductory section the reader learns how to navigate the blueprint in an effective way. **Figure 24** shows the individual paths that farmers/technology providers interested in diary, pig and broiler can take when navigating the blueprint. As we know that farmers and professionals have limited time to study this information we designed the blueprint to be read completely from start-to-finish in approximately 30 minutes. The typical division of this time across the different sections is shown in **Figure 24**. Of course, we acknowledge that some people would like further depth of understanding than what is available in the blueprint. For those this section includes a link to the Precision Livestock Farming e-course, which is a 8 hours course that covers PLF technology development and application more thoroughly.

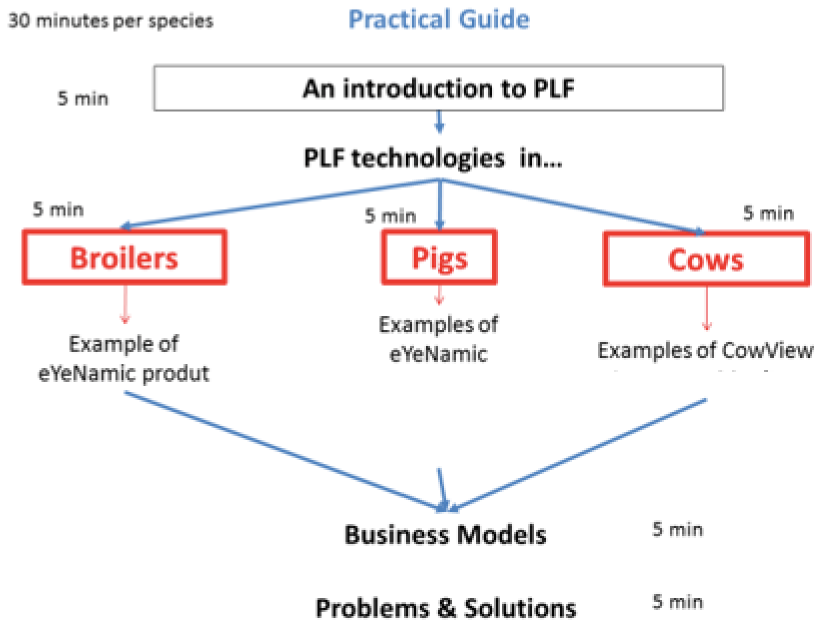


Figure 24: Blueprint logic line

A Blueprint for innovation in the European livestock sector has been created and published for all stakeholders to view. With the availability of this blueprint we hope to inform new companies interested in the PLF industry on how to go from an idea to an operational system at farm level. In this way the Blueprint can serve as a manual for farmers, their surrounding industry including high tech Small and Middle-sized Enterprises and other stakeholders. Full details on the Blueprint content are given in Deliverable 6.1.

5.0 Potential impact and main dissemination activities and exploitation of results

5.1 Potential Impacts

WP1 Determination of Animal Key Indicators (KIs) and Gold Standards (GSs)

The results of WP1 are lists of existing and new Key Indicators and associated Gold Standards in the domains animal welfare and health, productivity and environmental load, all of which can be measured with implementable PLF technologies. The new KI's will enable 3rd party technology providers to develop new systems to enable growth of PLF in the EU.

WP2 Extensive Field Tests

The results of WP2 are the selection and on-farm implementation of PLF systems to collect data on the animal in the domains animal welfare and health, environmental load and productivity. Results also include the design of Extensive Field Tests and subsequent data collection on the 20 farms in the project. Socio-economic impact is expected from the new knowledge attained by farmers and technology providers on how to properly implement and maintain these systems on farmers.

WP3 Data analysis, Integrated Solutions and PLF as a Service

The results of this WP are (1) data collected and analysed from the operative systems and (2) algorithms that automatically and in real-time translate measured animal responses to certain key indicators defined for the four domains and (3) the integration of these algorithms in the whole system structure of the farm. Business models are defined using the output of integrated systems (PLF as a service). Early detection of disease (as has been demonstrated by the use of the Pig Cough Monitor) can have huge implications in the reduction of the use of antibiotics and its consequences on animal and human health. Socio-economic impact is expected from the new technological developments, and new business models that give rise to the PLF service industry.

WP4 Definition of the Value Creation

The results of WP4 are the identification of social and economic value for different PLF applications on-farm and in supply chains. New modelling approaches have been developed to analyse (1) socio-economic data to identify value creation from farm measurements and (2) the value creation potential of the food supply chain (feed-animal-food) and (3) stakeholder-dependent social, and economic incentives for the adoption of PLF. The impact of the WP is its contribution to the understanding of the usefulness of PLF in economic and social terms, and the knowledge gained about the value of exchanging data along the feed-animal-food chain to unlock unused economic potential. Furthermore, quantifying the potential of social added value of PLF technology can allow the earlier adoption of PLF systems with the related social benefits (more time for the farmer, reduced stress, more balanced work/social life, increased social recognition, etc.).

WP5 Innovation through High-Tech SMEs

The results of this WP will be the identification of 4 high-tech SMEs with cutting edge PLF technology (2) the creation and training of spin-off companies to market/commercialise developed PLF technology, and (3) new prototypes that demonstrate valuable PLF application. We aimed at not only the initiation of the 4 start-up but also in awareness creation of the potential of the livestock sector and an application of high-tech solutions from other fields. This can lead to increased opportunities for entrepreneurs.

WP6 Creation of the blueprint

The results of this WP is a 30 minutes validated Blueprint that can be used as a guideline for actors in the value chain that want to use PLF technology. The blueprint is described using a generic approach but explicit examples are given to apply the generic approach in all possible PLF supported production systems. Socio-economic impact is expected from the knowledge gained by all stakeholders who will engage with the blueprint, as new technologies and applications are expected to emerge from this. The aim is for the Blueprint to transform the livestock sector into an innovative sector through the collaboration of high-tech SMEs with world market industrial companies

WP7 Dissemination

The results from this WP are (1) the creation of the EU-PLF website, and an established network community (via twitter and Facebook), (2) the creation of E-learning material (a 30 hours e-course for researchers and interested stakeholders), (3) the execution of workshops and an international conference, and (4) dissemination of the blueprint. Socio-economic impact is expected from the continuous communication with relevant stakeholders after the project, and well from the dissemination in the e-course and in Blueprint. This WP has convinced more farmers and farmer organisations of the potential of PLF technology and of the fact that their data are a future source of income.

5.2 Main dissemination activities and exploitation of results

Dissemination of the blueprint

The EU-PLF Blueprint is targeted at farmers and PLF providers seeking information on PLF technologies and the value they bring to the farmers. The PLF e-Course aims to give more scientific insight in the principles of PLF technology for researchers, students, teachers and other people seeking more in-depth knowledge. The EU-PLF Blueprint and the PLF e-course are accessible from a common web platform.

It was an agreed decision by the EU-PLF partners that both the EU-PLF Blueprint and the PLF e-course would be available on the website of the project and after the project these developments would be transferred to the European Association of Precision Livestock Farming (EA-PLF). The EA-PLF is the previous European Committee for PLF that now turns into an official non-profit organisation the EA-PLF to support and disseminate research in PLF. Several countries have representatives for the last 13 years and the Committee has organised the 7 previous EU-PLF conferences and will keep doing so in future.

- The most important conclusion after the EU PLF project is that the project has demonstrated that the *PLF technology indeed can be implemented in real farms* in an operational way. It shows that the real-time collection of animal data and running early warning or managing software is not utopian but has become a reality. Before the project many scientist had doubts and criticisms but the project has proven what is technical possible in a digitised livestock sector where Internet of Things is now emerging.

- The EU-PLF project is the first European PLF project at this scale with *such serious and active involvement of farmers.* Farmers participated in the workshops, the discussions, the presentations with a very open minded state of mind and critical but constructive attitude. This shows how important it is to involve farmers in this type of projects. The farmer is the first and only stakeholder who depends so much on the health, welfare and productivity of his animals. He/she is the one that should not be blamed for the way they make their living but should be considered as a real partner. We could learn a lot from the participation of these key people in the livestock process.

- The high flow of data has shown us that it is just *not realistic to store all measured data* but that algorithms must run at the lowest possible level to filter out relevant information, which can then be passed to the higher level. It is quite important to understand that sending large volumes of data has a large energy demand as well as cost of data storage. Therefore, it is more important for *information* to be considered at higher level and not all the raw data. This is important when it comes to Big Data analyses, and helps in defining how to approach this opportunity in the livestock sector.

- During the project a lot of work was done as described in the report to find new key variables and feature variables to develop new *algorithms.* For broilers it has been shown that the eYeNamic camera system can detect over 90 % of all problems and give a warning. For fattening pigs the SoundTalks system can give an early warning for infection 2 to 12 days before the farmer noticed. For dairy several new key indicators and applications were demonstrated. The work presented for livestock show that basic signals can provide very useful information when processed adequately. From real time monitoring of animals, we could produce new KIs in relation to welfare and management. It is clear that more work will come and more powerful algorithms will be developed. The *continuous (24 hours & 7 days) and fully automated monitoring of animal behaviour and variables is possible and a strong advantage* for process management when it comes to guarding animal welfare, health and productivity. The potential of PLF on environmental impact needs more attention.

- Although several possibilities have been shown and new ones have been developed the *economic advantage of this technology will need more time to be proven in practice at a wider scale.* Estimations have been given and methods have been developed as they are offered in the EU-PLF Blueprint. The application of these approaches have to be experiences on more farms and have to be realised on a higher scale in practice to get more hard economic figures.

- A key issue to be worked on is the most appropriate business model for the PLF technology. At the moment that the whole industry and all stakeholders are dreaming of their position in a worldwide global approach with Internet of Things and Big Data nobody from small to big company or whatever stakeholder has already a clear view on the business model they should apply. In this the opportunities for farmers to generate a new resource for income by selling data for generation of information is underestimated and not seen yet. The type of juridical contract and the stakeholder that will offer this to farmers must be clarified to make PLF growing in the worldwide livestock sector. Farmer's organisation and farmers unions will play a key role and need to understand their position within the whole scheme.

- Besides the economic advantage and possibilities the PLF technology offers *important social advantages* as explained by the farmers: more peace of mind, possibility to participate more in community events without always staying at the farm, transparency in how farmers make their living.

- The project has demonstrated that *EU is ahead in the development and application of the PLF* technology and the effect can already be seen with the first PLF conference in China, in Brazil, in Mexico in US. The good news is that the organisations in China, Brazil and US are happening in agreement with the European Association of PLF. In the worldwide increase of the demand of animal products Europe might not deliver the cheap bulk meat to be used in China, India, South America and Africa but Europe can deliver knowledge in technology for the hug market of animal products.

- The project has realised the *challenging deliverable of starting 4 new companies in PLF*. The livestock sector has to be turned into a high tech sector that is attracting young people. The project has today delivered these 4 new companies with 25 people working in a high tech sector for a hug worldwide market. Many young entrepreneurs might have very interesting technology with potential application in the livestock sector but we have to make them aware of this great market opportunities to valorise European science and technology.

6. Overall recommendations

- Modelling allows forecasting the behaviour of farm animals and developing an early warning system to the farmer, thereby offering possibilities to act on a disorder at an early stage and thus more efficiently. In all species, it is possible to foresee PLF being applied at individual level allowing fine tuning of the management of each animal. PLF is a strong tool to manage the process more close to the genetic potential of the animal in terms of more animal products with less feed and less manure. More research is needed to realise this.

- During EU-PLF we found that the expertise of the farmer is essential for this to be realised. Further work is required to integrate technologies with the expertise of the farmer PLF systems for farmers, thereby adopting a “farmer-in-the-loop” approach to PLF development.

- This work opens many possibilities for further developments of PLF techniques based on real time monitoring of animals: For example in dairy applications, the exact behavioural profiles of cows under various health disorders need to be distinguished (e.g. alteration of the rhythm or of specific activities such as comfort activities…); Thresholds shall be defined to send appropriate alarms to farmers; The daily budget and rhythm of activity could be modelled to detect anomalies; The relation between a cow’s behaviour and its milk yield as an indicator of its longevity should be further investigated; Networks between animals could be identified to understand the spread of diseases; Algorithms to detect interactions between animals or responses to humans should be investigated, PLF offers the potential to collect data on very high numbers of animals to be connected to the genetic line which opens a totally new world of opportunities to gain understanding and improving the efficiency of the process.

- In order to gain the most from research in the livestock sector it is essential that a good a real close collaboration between researchers from different disciplines (e.g. engineers and natural scientist). Many researchers are just not interested in turning science into money since they are used that money turns into research. More projects should get a deliverable related to valorisation.

- More projects should try to involve young entrepreneurial people to start up spin-off activities guided by professional people in this matter as shown in this project with the important effect that also the scientists understand that bringing their knowledge to valorisation is an important contribution to the European society.

- EU projects take a lot of money and the normal way should be that a project coordinator does not distribute money if results are not delivered. Apparently some researchers are very surprised if this principle is applied.