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# Automatically collected data in cattle, pig and poultry farming

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Generating a large amount of data offers many opportunities for optimising animal husbandry. To facilitate production and animal management, the manufacturers of sensor technology define target characteristics to be captured. Automatic components and entirely automated systems are implemented in barns to determine key indicators related to the productivity, health status, fertility status and behaviour of animals. In addition, they capture data on the technology used to control animal movements and other processes. Automated data collection thus allows the continuous evaluation of animal-related data, climate/environmental data and data on the technical equipment. A comprehensive database was compiled on sensors for „automated data collection in livestock husbandry" (AutoDatTier) in order to identify and describe sensor technologies for each of the animal species: cattle, pigs and chickens. The database includes additional information on the sensor type, functional principle, measurement type, data type and quality as well as the source of the data and evaluation (a total of 19 criteria). Sensors are technical components that use physical or chemical effects to capture physical, chemical or electrochemical variables and convert them into electrical signals. Depending on the manufacturer or software, the data can be output in graphical, tabular or text formats. Evaluations of the sensor technology used in agricultural animal husbandry provide detailed insights into the current spectrum of manufacturers and sensor systems on the market. Based on this information, opportunities and deficits in livestock husbandry can be derived, and future research projects can be aligned accordingly.

**Keywords**
Sensor technology, livestock farming, animal data, environmental data, equipment data

A large number of diverse sensor systems for automatically capturing data and information are commercially available. However, their application and adoption varies depending on the animal species. These technologies continuously capture various parameters in real time. On the one hand, they serve to improve animal welfare and protect the environment; on the other hand, they can also be used to optimise farm management, improving the economic and social situation.

To this end, researchers are pursuing and developing comprehensive approaches, both nationally and internationally. Data on individual animals are available, especially in cattle farming. Activity sensors and other sensors provide values on oestrus, calving, feed intake and animal health. The automatic collection and analysis of data on the quantity, composition and quality of milk (integrated as a standard feature in automatic milking systems) provides crucial insights into the productivity potential of each cow and enables early detection of udder diseases. Automated feeding is made possible by feeding robots. Additional indicators allow verification of whether feed rations are adapted to the animals' needs. Both in barns and pasture settings, feed supply can be controlled using automatic

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grazing systems. At pre-programmed intervals, these systems can be used to move fences, giving animals continuous access to fresh green fodder. These are some examples that have already been successfully implemented in practice. Review articles are particularly well-suited for gaining a quick overview of the various methods and outcomes (Reith and Hoy 2017, Rutten et al. 2013, Zhang et al. 2013). There are also a number of labour- and time-saving benefits to using sensor systems. Planning software or herd management programs allow critical aspects to be monitored and support decision-making, additionally enhancing the quality of work. Furthermore, data can be used for product safety and production control purposes (process documentation, transparency and traceability) (Kamphuis and Steeneveld 2016, Pollmann 2017).

Similarly, automated systems are used in poultry and pig housing to check productivity, health status and feeding as well as to control the climate. However, fewer technologies are available than in cattle farming. In many cases, the systems monitor groups of animals rather than individual animals (Van Hertem et al. 2017). A project commissioned by the German Association for Technology and Structures in Agriculture (KTBL) and carried out by the Thünen Institute of Agricultural Technology determined the data to be automatically captured in livestock farming. Funded by the KTBL „Calculation Documents" work programme, which is supported by the federal and state governments, the project aimed to develop an extensive database in which the different sensors used in livestock farming – i. e. cattle, pig and poultry farming – are listed and described.

## Materials and methods

The basis for compiling a database of the sensor systems available for livestock farming globally was an extensive directory of companies, which was processed at the Thünen Institute from February 1, 2018, to December 15, 2018. The first step involved chronologically processing the directory of exhibitors at the world's largest trade fair, EuroTier, held in 2016. Sponsored by the German Agricultural Society (DLG) since 1993, EuroTier is organised at two-year intervals in Hannover by DLG Service GmbH. In 2016, there were approximately 2,638 exhibitors at the fair; 43 % of the companies were headquartered in Germany, and 57 % outside of Germany. To efficiently identify sensor systems for automated data collection in animal husbandry in the database of companies, a pre-selection was carried out using filters for „cattle", „pigs" and „poultry". This pre-selected database included 824 companies, which were then analysed by means of detailed literature and internet research to identify the available sensor technology. If the search result was positive, the sensor system was entered into the corresponding sensor database. However, a number of companies publish only limited or, in some cases, no information about their sensor technology online. Hence, a secondary data collection phase was performed, which involved conducting interviews with the respective technology companies. The database was subsequently revised accordingly. Additionally, double entries in the database (some companies offer a sensor technology for several animal species) were corrected, resulting in a final dataset of 149 companies. The sensor database only included market-ready and commercially available systems. Technologies that had been successfully implemented in studies and pilot installations, but were not mature or available for end users were not included.

## Basic structure of the sensor database

To categorise the various sensor systems, the database structure shown in Table 1 was chosen. The sensors were first assigned to the specific animal species and corresponding type of production, allowing multiple assignments. The other columns list the type of data and the subject of data collection. With regard to the latter, it was possible to distinguish between specific and non-specific individual animals and specific and non-specific groups of animals. Capturing data on a specific individual animal is only feasible when a sensor system is able to detect an individual animal in an error-free and repeatable manner or is coupled with such a sensor. If this is not the case, the collected data refer to a non-specific individual animal, and it is not possible to determine whether a specific animal has been recorded several times or several animals have been recorded successively. When data are collected from a physically separate animal area, they pertain to a specific animal group.

If a sensor collects data in an entire barn and the data cannot be attributed to a specific group of animals, they pertain to a non-specific group of animals (Part A). As a rule such data are collected on the technical equipment and climate. To allow a detailed description of the sensor systems and their environment, a total of eight individual characteristics were recorded in the database (Part B). In addition, information on the data source that provided the data was collected in the database. To describe the recorded sensor data within the described data sources, one of three criteria could be selected to allow a consistent representation (Part C). Firstly, the file format used to display and access the data was characterised. This involved distinguishing between audio, graphical, geodata, tabular, text and other formats; multiple selections were possible. Another criterion was an assessment of the quality of the data; the quality levels presented in the table consitute an assessment of whether the data obtained are reproducible. The „willingness to share data“ was determined based on whether the recorded sensor data could be exported. Here, the criteria „yes“, „no“ or „unclear” could be selected; furthermore, it was possible select „conditional“ if further hardware or software is required to export the data (Part C).

Table 1: Basic structure of the sensor database

(Part A)

| Animal species | Type of production | Data collection | |
|---|---|---|---|
| | | Data type | Subject |
| Cattle | Young cattle rearing | Animal-related data | Specific individual animal |
| Pigs | Dairy cow husbandry | Climate/environmental data | Non-specific individual animal |
| Chickens | Suckler cow husbandry | Technical equipment data | Specific group of animals |
| | Beef fattening | | Non-specific group of animals |
| | Piglet production | | |
| | Piglet rearing | | |
| | Pig fattening | | |
| | Pullet rearing | | |
| | Keeping of laying hens | | |
| | Chicken fattening | | |
| | Universal | | |

(Part B)

| Type of measurement | Sensor type | Manufacturer (sensor) | Sensor name | Electron. component | Functional | Practical sampling rate | Data quality |
|---|---|---|---|---|---|---|---|
| Principle | | | | | | Continuous | Very low |
| | | | | | | 1/s – 59/s | Low |
| | | | | | | 1/min – 59/min | Medium |
| | | | | | | 1/h – 59/h | High |
| | | | | | | 1/d – 24/d | Very high |

(Part C))

| Data source | | | | Data description | | |
|---|---|---|---|---|---|---|
| Display device | Manufacturer (software) | Software name | Brief description | File format | Reproducibility | Daten-export |
| PC | | | | cibility | Data | Yes |
| Smartphone/tablet | | | | export | Sufficient | No |
| Online communication device | | | | Geodata format | Low | Conditional |
| Manufacturer's PC | | | | Tabular format | Unclear | Unclear |
| | | | | Text format | | |
| | | | | Other | | |

## Results and discussion

### Companies offering sensor technology for livestock farming

The leading companies in sensor technology are primarily located in Europe. In the project, 149 companies offering commercial sensor technology for livestock farming were identified (Figure 1). They are based in 25 different countries: 134 (90 %) located in Europe, including the 95 strongest companies. The remaining 39 European companies that were not mentioned separately in the figure are summarized as the rest of Europe. Germany has the highest number of companies providing sensor systems (47), 32 % of the total. The Netherlands is the second-strongest supplier of sensor technology for livestock farming, with 22 companies (15 %). France and Italy occupy third place with nine companies each (6 %), ahead of the UK where eight companies (5 %) are located. The remaining 15 companies (10 %) are based in six other countries in the Americas, Asia and Oceania (New Zealand).

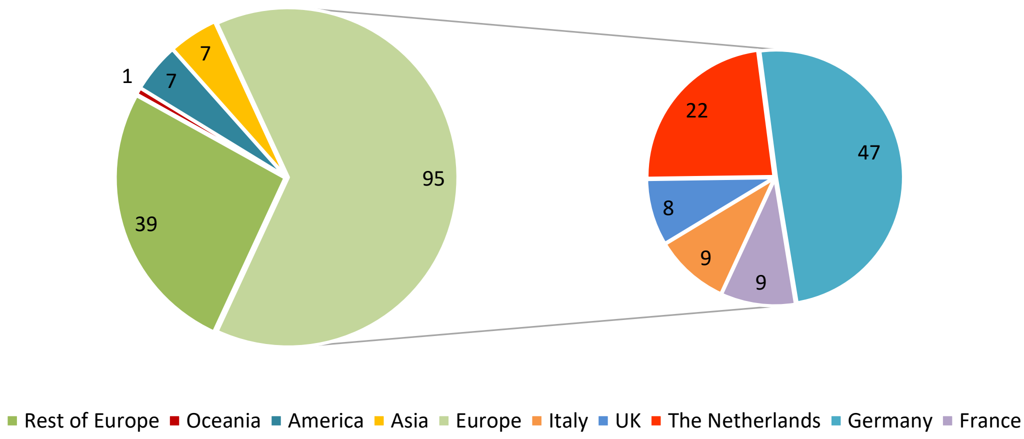


Figure 1: Distribution of companies with sensor technology by country

### Sensor technologies for cattle, pig and poultry farming

A total of 355 records of sensor systems and their associated peripherals were identified. The sensors were initially assigned to the animal species: cattle, pigs and poultry. The highest number of sensors, 120, are used in cattle farming, accounting for 34 % of all sensors. A total of 101 sensors (28 %) are implemented in poultry farming, while 63 sensors (18 %) are used in pig farming. Additionally, 71 sensors (20 %) can be used universally for all animal species (Figure 2).

Depending on the type of production, the application of the different sensor technologies varies (Figure 3). In cattle husbandry, by far the most sensor systems available on the market are designed for use in dairy cow farming (see also Table 2). Sensors are used less frequently for monitoring and controlling the fattening and rearing of cattle, for example, in systems for determining feed consumption, milk quantity and animal weight. As some manufacturers offer technologies implemented in several types of production, there are some double entries. In addition, the same technology used in systems produced by different manufacturers also results in double entries.

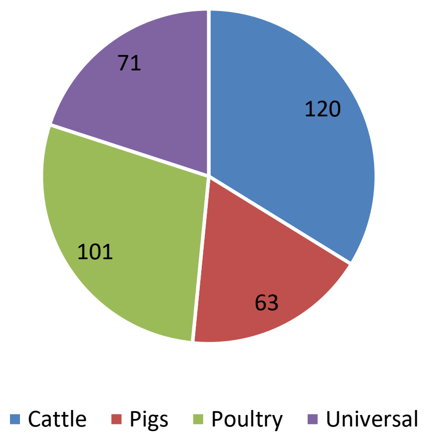


Figure 2: Number of sensors depending on the animal species

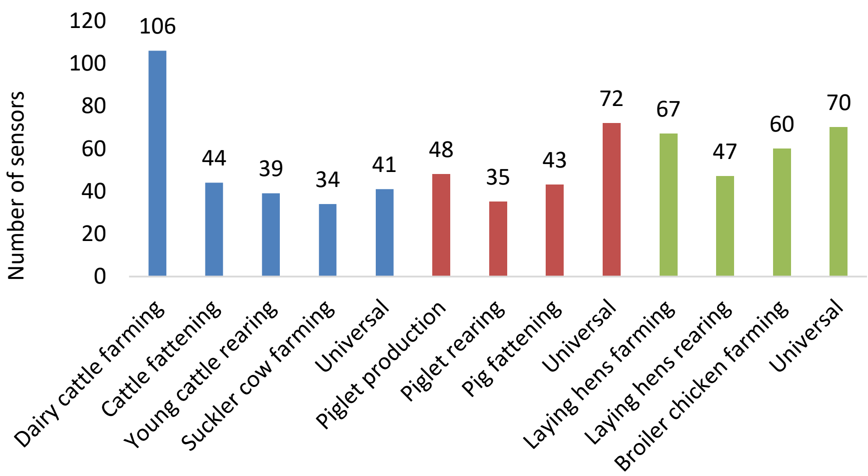


Figure 3: Number of sensors for the different production types in cattle, pig and poultry farming

In pig farming, sensor technologies are most frequently used in piglet production. Systems for measuring the piglets' feed consumption and detecting their oestrus behaviour are mainly deployed (Lee et al. 2019, Gaillard et al. 2020). In pig fattening, sensors for measuring the individual animals' weight are more common.

For the species of chickens, most digital systems are used in the rearing of laying hens. For example, animal-related systems are deployed for counting and weighing eggs and detecting cracks in eggshells. In broiler chicken farming, however, methods for determining the individual animal live mass play a more important role. Only one animal-related technology – a technology measuring an embryo's heartbeat in eggs – was identified in poultry rearing. On the other hand, in pig and poultry farming, most sensors can be universally implemented in all types of production. They capture data on the climate, environment and technical equipment.

## Animal-related data

Animal-related data primarily provide information about the productivity, health and behaviour of an individual animal or group of animals, thus generating insights for their husbandry and management. The individual technologies can be assigned to different application areas (Table 2). In dairy cow husbandry, technologies are already being successfully implemented for measuring cows' activity, determining daily rumination time and assessing various physiological parameters, such as the ruminal pH or body temperature (Umstätter et al. 2020). According to insights from different scientific studies and/or information provided by manufacturers, some systems – such as those that determine the daily rumination time – are able to detect multiple aspects. For instance, they can detect metabolic diseases (Devries et al. 2009) and oestrus (Reith and Hoy 2012) as well as predict calving dates (Pahl et al. 2014).

Monitoring of individual animals has advanced more and more since the 1980s. The development of electronic transponders for recognising individual animals was followed by the introduction of sensors for detecting various diseases (udder diseases, hoof diseases and metabolic disorders) and oestrus behaviour. A detailed overview of the history of sensor-based animal health management was provided by Rutten et al. (2013), who reviewed a total of 126 studies.

Likewise, a number of digital systems are used for monitoring animals in pig sties and poultry houses (Matthews et al. 2016, Sassi et al. 2016). Information on behavioural changes that typically precede or accompany sub-clinical and clinical signs are useful for diagnostic purposes. Similarly to in cattle farming, such information includes deviations in feed and water intake behaviour, excretory behaviour, social behaviour was well as changes in movement and posture.

Table 2: Selected animal-related parameters for monitoring animal productivity and health in dairy cow husbandry

| Application area | Parameter | Technology |
|---|---|---|
| Animal identity | Animal number | RFID transponder |
| | Position | Ear tag transponder<br>Collar with radio sensor |
| Animal health | Activity | Pedometer (step count)<br>Respactor (neck/head movements)<br>Video camera |
| | pH value | pH sensor in the reticulum |
| | Body temperature | Ear tag with temperature sensor<br>Temperature sensor in the reticulum |
| | Foot pressure | Force plate<br>Pressure sensor mat |
| Feeding | Staple feed intake (quantity, frequency) | Weighing trough |
| | Concentrate feed intake (quantity, frequency) | Concentrate feeding station<br>Weighing trough |
| | Rumination time,<br>number of chewing cycles | Collar with acoustic sensor (microphone)<br>Halter with pressure sensor<br>(liquid-filled tube in noseband) |
| | Water intake<br>(quantity, frequency) | Weighing trough |
| | Body condition | Video camera (3D videos) |
| | Live weight | Waage, Teilwaage |

Table continues on next page

| Application area | Parameter | Technology |
|---|---|---|
| Reproduction | Activity | Pedometer (step count)<br>Respactor (neck/head movements)<br>Video camera (jumping behaviour)<br>Tracking systems |
| | Rumination time | Halter with pressure sensors<br>Collar with acoustic sensor (microphone)<br>Ear tag with acceleration sensor |
| | Feed/water intake | Weighing trough |
| | Lying time | Pedometer with position sensors<br>Ultrasonic sensors |
| | Vocalisation | Collar with acoustic sensor (microphone) |
| Product | Milk quantity | Various measuring devices or as part of the AMS[1)] |
| | Milk constituents (protein, fat, urea, lactose, hormones) | Various measuring devices or as part of the AMS |
| | Physical measurements<br>(e. g. conductivity, colour, temperature) | Various measuring devices as standard equipment in the AMS or as additional equipment |

[1)] AMS: Automatic milking system.

## Environmental and climate data

In modern animal husbandry, climate control is an essential part of housing systems. Especially in forced-ventilated pig sties and poultry houses, the climate directly impacts the health and well-being of animals and is thus an indicator of productivity level. When assessing the climate in animal housing, various factors beyond the animal species, type of production and animal productivity need to be considered. Additionally, aspects such as the age and type of housing system as well as the duration and intensity of exposure to a housing climate should also be taken into account (Möbius 2010). Real-time monitoring of data ensures that optimal climate conditions are maintained in the housing – including adjusted air mass exchange and temperature control, regardless of the weather conditions and emissions from the animals and the equipment. Digital controllers provide precise values, allowing farmers or systems to react immediately. Essentially, the climate in animal housing is determined by the following factors: the air temperature, air humidity, air velocity and concentrations of harmful gases (Table 3). For example, if the humidity is too low, it negatively impacts the animals' respiratory system. Conversely, excessively high levels of humidity lead to water condensation in the barn, favouring the formation of mould and corrosion and hindering heat dissipation from the animals. Ammonia plays a major role as a harmful gas. Even at low concentrations, it can irritate the mucous membranes of the respiratory tract and the conjunctiva of the eyes. Health and productivity impairments can be expected with ammonia concentrations from 30 ppm in the air in housing (Bachmann 2010). Emissions can be measured using specific gas sensors that generate electricity which is linearly proportional to the gas concentration.

Table 3: Selected parameters for monitoring the climate in housing

| Application area | Parameter | Technology |
|---|---|---|
| Air in housing | Air temperature | Thermometer |
| | Humidity | Hygrometer |
| | Air velocity/wind direction | Anemometer |
| | Air pressure | Barometer |
| Light | Illuminance | Lux meter |
| Harmful gases | Ammonia | Specific gas sensor |
| | Carbon dioxide | Infrared sensor |
| | Carbon monoxide | Infrared sensor |

## Data on equipment

In addition to monitoring the animals and the climate in housing, sensor systems comprehensively monitor machinery and technical equipment (Table 4). The project results indicate that various parameters, especially in the area of feeding, are continuously and automatically recorded and analysed. Sensors can be permanently installed in a facility, and some sensor systems can also be used seamlessly across different machines (balers, combine harvesters, forage harvesters, loading and feed-mixer wagons) to control the quality of a crop. They allow „on-farm“ analyses, for example, of feed ingredients (e.g. ADF, NDF, starch, ash, crude fat, moisture). Water analyses are carried out to ensure sufficient water intake and, thus, animal health as well as to monitor the cleaning of feeding systems. Furthermore, in practice, it is essential that the water pressure and volume flow rate in the pipelines of watering systems are measured using electronic flow meters. This measurement is also used for adding medication or nutrients to drinking water and for administering vaccines in the drinking water.

Table 4: Selected parameters for monitoring technical systems

| Application area | Parameter | Technology |
|---|---|---|
| Feeding | Feed consumption | Load cell/tipping bucket |
| | Feed quality | Near infrared spectroscopy |
| | Filling level of feeding pipes | Full indicator/proximity switch (detection of full/empty state) |
| | Water consumption | Water meter |
| | Water quality | Digital camera with image sensor/biofilm sensor |
| | Water pressure | Flow meter |
| Electricity supply | Stromverbrauch | Electricity meter |
| Product | Milchtemperatur | Thermometer |

The majority of commercially available sensor systems can be used to collect animal-related data. Data on the climate/environment and on the equipment are the second and third most frequently collected data categories (Figure 4). Animal-related data are predominantly gathered in cattle farming, with a share of 58 %. Conversely, for collecting and controlling data on the climate and environment, 49 % of sensors are implemented in poultry farming. Similarly, sensor data are mainly used for mon-

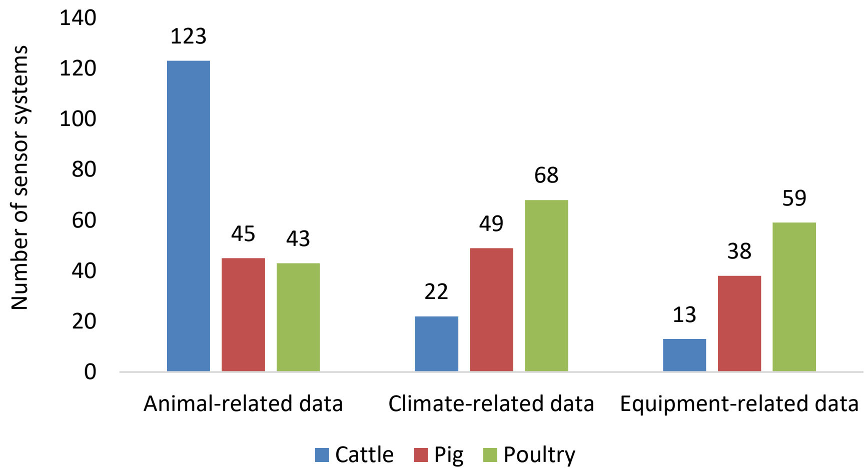


Figure 4: Distribution of data types by animal species

itoring technical equipment and machinery (54 %) in chicken farming. On the other hand, collection of data on the climate/environment and on technical equipment plays a rather minor role in cattle farming.

In cattle farming, the focus is on data pertaining to specific individual animals, with 91 sensors devoted to this purpose. The database contains 13 sensors for automatically collecting data in specific groups of animals. The other types of production account for between 15 % and 20 % of the total number of sensors. Sensors that can be used in all of the above areas were assigned to the category „universal". In poultry farming, most sensors can be used universally in all types of production. Data are most often collected on specific groups of animals, with 121 sensor systems dedicated to this. Sensors for recording data on specific individual animals were not identified in poultry farming (Figure 5).

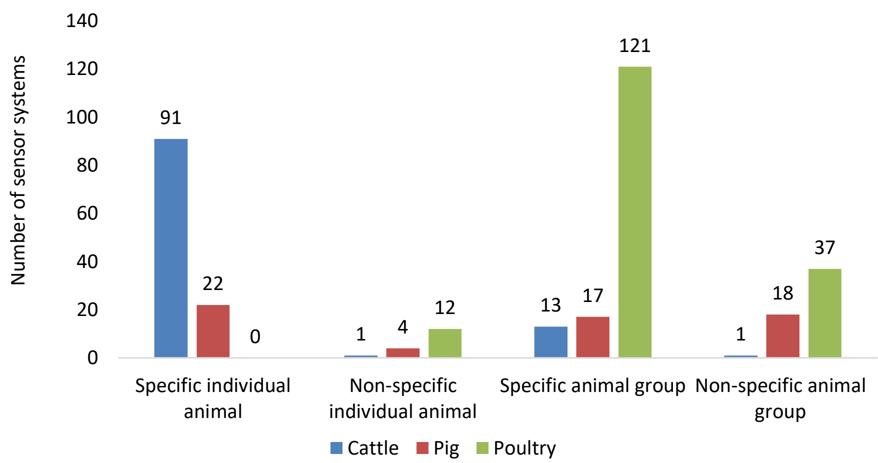


Figure 5: Distribution of sensor systems by subject of data collection in cattle and poultry farming

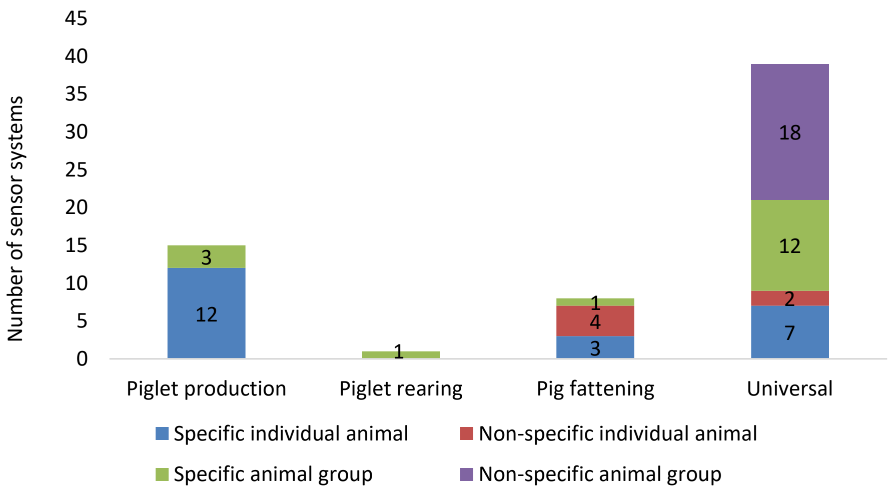


Figure 6: Distribution of sensor systems by subject of data collection in pig farming

In pig farming, the majority of sensors (for capturing climate/environmental data and data on technical equipment) can be used universally in all types of production. Data are most often collected on non-specific groups of animals, with 18 sensor technologies implemented for this purpose. However, sensors for recording data on specific individual animals were also identified in pig farming (Figure 6).

Gaillard et al. (2020) explain the potential of modern feeding technologies and predictive models that allow animals housed in groups to be fed according to their individual needs, improving the efficiency of the group. Precision feeding strategies are a promising solution for growing pigs as they allow the nutrient supply of each individual animal to be adjusted at different time points, reducing nutrient excretion. Recent simulations suggest that precision feeding may also be a relevant strategy for sows.

In general, measuring devices make a vital contribution to animal welfare, environmental protection and economic efficiency (Banhazi et al. 2012). Smart, intelligent and valuable information can be extracted from all relevant data (Berckmans 2014, Monteiro et al. 2017).

## Conclusions

The benefits of the database are manifold. Firstly, it provides a detailed overview of the specific sensor systems used in livestock farming which can be compared with each other. For example, livestock farmers seeking to identify and integrate technologies that meet their requirements can profit from referring to it. In addition, it allows identification of the areas in which no systems are available to livestock farmers. In this way, research institutions or industry can derive the research needs. It should be noted that the database can only be assumed to be complete if it is continuously updated, as the sensor technologies used in livestock farming are permanently being developed further and improved.

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