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DIGITAL TRANSFORMATION OF ANIMAL HUSBANDRY – PROBLEMS AND OPPORTUNITIES

ABSTRACT

of a dissertation for awarding the educational and scientific degree of "Doctor"
in the doctoral program "Economics and Management (Agrarian Economics)"

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I. GENERAL CHARACTERISTICS OF THE DISSERTATION

1. Relevance and significance of the research problem

In today's era of innovation, the agricultural sector is undergoing transformative change, with digitalization driving attention toward a more sustainable and efficient future. Animal husbandry, as a centuries-old practice key to human civilization, finds the threshold of this digital revolution., and exploring how cutting-edge technologies are redefining livestock care, management, and welfare.

The study covers the potential opportunities for digital tools and data analytics to not only expand traditional practices but also foster a new era of development. From portable sensors that monitor health indicators in real time to AI-driven decision-making platforms that optimize breeding patterns, the digital environment is changing the animal husbandry landscape.

This study aimed to provide a comprehensive overview of current digital trends, their practical applications, and their potential to increase productivity while ensuring animal welfare. This dissertation seeks to respond to the challenges and ethical considerations that arise in the application of innovative technologies, offering a balanced perspective on the future of agribusiness.

The relevance of this development is due to the need to increase the profitability and competitiveness of Bulgarian livestock breeding. This research was conducted in an ever-changing dynamic environment. These issues are significant for theory and practice in the field of digitalization in the management of livestock farms, with an emphasis on specific problems and challenges in the implementation of digital solutions, as well as sustainable models for intelligent and efficient animal husbandry. It should be borne in mind that livestock businesses worldwide are facing a complex combination of technological revolution, climate change, and aggravated political environment.

2. Subject and object of the study

The subject of this study is digital tools and the use of artificial intelligence (AI) for more cost-effective and environmentally friendly management of livestock farms and the realization of production (meat).

The object of the study is the opportunities and challenges in the digitalization and construction of the "IDEAL FARM" with its own feed and realization (meat direction).

3. Purpose and objectives of the study

The main objective of the dissertation on "Digital transformation of livestock breeding – problems and opportunities" is to develop and validate a comprehensive framework for planning, implementation and evaluation of digital transformation in animal husbandry, allowing for informed management decision-making and sustainable added value in various production and institutional conditions.

The following research tasks were formulated in connection with the set goals:

- **In theoretical aspect – 4 pieces**

1. Theoretical analysis of the opportunities for digitalization of the livestock business in Europe and its national scope
2. Systematization of a list of technological possibilities for digitalization and optimization of the processes from feed preparation to the sale of production (meat);
3. Optimization of the processes in the management of livestock farms, slaughterhouses, and meat processing plants, taking into account the specifics of cattle/buffaloes, sheep/goats, and pigs.
4. Creation of a classification of farms according to the stages in the agri-food chain in which they participate according to the different business models

and types of animals raised. Assessment of the possibilities of technological solutions from the perspective of economic feasibility.

- **In practical aspect - 3 pieces**

1. Study of different farms by comparing them with established classifications. We defined the typed company profiles.
2. Implementation of ERP system or hardware innovations and comparison of results.
3. This takes into account the degree of digitalization, challenges, and opportunities for future development.

4. Main research thesis and hypotheses

The research thesis that is defended is that through the use of properly selected and qualitatively implemented digital methods and interconnected innovative technologies, it is possible to increase both the quality and profitability of production while minimizing the impact on the environment.

This study is based on the current state of the software and hardware solutions of a specific innovative company working in the field of digital technologies. The implementation of an integrated ERP system in animal husbandry provides grounds for ongoing research through individual solutions on modern farms, depending on their profile. The goal is to achieve a higher level of sustainable model of the "**Ideal Farm**."

The research and presentation of the study results are based on the following **hypotheses:**

Hypothesis A – The digitalization of a livestock farm depends on its size, the type of animals that are kept, their breed and direction, and the technology by which they are raised.

Hypothesis B: The digitalization strategy in each individual farm should be carefully selected depending on the form of management and the views and qualifications of the owners and management staff.

Hypothesis C – Software solutions for control and management of the livestock business by the state are of key importance to the speed and direction of business digitalization.

Hypothesis D: The livestock business support system creates prerequisites for serious discrepancies and incorrect practices due to the lack of a sufficient level of digitalization on the farm.

Hypothesis D – tracking the process "from field to fork" and the quality of production is achievable with the digitalization of all processes along the chain.

II. STRUCTURE AND CONTENT OF THE DISSERTATION

The dissertation consists of 265 pages, of which: introduction (5 pages); exposition in three chapters (234 pages); conclusion (3 pages); References (15 pages) The main text contains 36 figures and 24 tables The list of references consists of 160 sources.

The dissertation is structured as a list of abbreviations used, a list of figures used, a list of tables used, an introduction, three chapters, a conclusion, and literature in which the logical sequence of its content is examined.

III. MAIN CONTENT OF THE DISSERTATION

CHAPTER ONE - THEORETICAL FOUNDATIONS OF DIGITAL TRANSFORMATION IN MODERN ANIMAL HUSBANDRY

In the first point of Chapter One, an overview is provided and the ***general characteristics of digitization in the livestock business are formulated – the directions: identification, traceability, and automation***.

The definition is formulated that Digitalization in animal husbandry is a set of measures that must be adopted at different levels in order to achieve a successful digital transformation of the sector. These measures include organizational and logistical, technological, educational, and legal measures.

Digitalization in animal husbandry is often associated only with ease of animal husbandry processes, such as monitoring, nutrition, healthcare, breeding, and transport, which is a very limited view. Digitalization can affect various aspects of agricultural enterprises, such as **planning**, **control**, **optimization**, monitoring, **evaluation**, **management**, **compliance**, **communication**, **and marketing**.

A comparative analysis of different methods of digitalization in animal husbandry, which are applied in Europe and the world, was formulated, showing how they differ in terms of goals, technologies, results, and challenges.

Paragraph 1, point 1 of Chapter One, discusses ***the methods of digitalization in animal husbandry.***

"Methods of digitalization in animal husbandry include the use of various technologies such as portable sensors, automated monitoring and control systems, artificial intelligence and the Internet of Things, which help collect and process data about animals and production processes." (White & Brown, 2021, p. 48). In addition, "New approaches to digitalization in livestock farming include the use of innovative technologies such as machine learning and blockchain, which

provide new opportunities to improve the efficiency and management of livestock processes." (Johnson & Smith, 2020). 80).

After a thorough study of the documentation, the methods of digitization in animal husbandry are summarized in Table 1.1.

Table 1.1. Methods of digitalization in animal husbandry

Term in Bulgarian	International term	Abbreviation
Precision Animal Husbandry	**Precision Livestock Farming**	**PLF**
Intelligent livestock management systems	**Smart Livestock Management Systems**	**SLMS**
The Internet of Things in Animal Husbandry	**Internet of Things in Livestock**	**IoT-L**
Blockchain in animal husbandry	**Blockchain in Livestock**	**CAR**
Artificial Intelligence in Animal Husbandry	**Artificial Intelligence in Livestock**	**AI-L**

(*source: Internet*)

A SWOT analysis of the different methods was performed.

Special attention has been paid to the possibility of using Artificial Intelligence in Animal Husbandry (**AI-L**). **Artificial intelligence is a digitization method that uses computer algorithms that can simulate human understanding, training, and problem-solving to collect, analyse, and use information about various aspects of livestock farming, such as production process management, finance, administration, planning, control, and documentation**. The use of Artificial Intelligence allows the optimization of a large part of the processes, completely replacing human resources or helping to make management decisions by low-qualified personnel. Naturally, the long-term replacement of human resources in the long run can create negative social terms.

The goal of AI-L is to improve livestock management, increase intelligence and automation, share data and knowledge, facilitate collaboration, and support decision making. AI-L allows livestock breeders to have better access to and control over information pertaining to their activities and use it more efficiently and intelligently.

Paragraph 2(1) of Chapter One examines ***the types of digital technologies used in the livestock business***, formulates a definition and creates **a** detailed classification.

Digital technologies refer to the use of information and communication technologies (ICT) to collect, process, analyse, and communicate data and information related to livestock farming and management. Digital technologies can be classified into four categories: monitoring, data processing, decision support, and communication (Fuentes et al. 2022). They are:

- **Sensor technology** is a combination of devices and data collection methods that measures and monitors various parameters of animals, such as their location, movement, behaviour, health, and performance.

Its own classification **was generated** to evaluate different types of sensors and their cost-effectiveness.

Table 1.2 - Comparison between different types of sensors

Decision	Initial investment	Profitability
RFID Tags	Low to medium	Low to medium
GPS Collars	Medium to high	Medium to high
Cameras	Medium to high	High
Microphones	Low to medium	Low to medium
Biosensors	High	High

(*Source: Author's study*).

- **Data processing technologies** include software and algorithms that store, manage, and analyse data collected using sensor technologies.

Various examples of data-processing technologies include cloud computing, big data analysis, artificial intelligence (AI), and machine learning (ML).

- **"Decision support technologies** in animal husbandry are intelligent systems that analyse data from various sources and provide recommendations for managing livestock processes. The derivative formulation that **decision-support technologies include tools and methods that assist farmers and other**

stakeholders in making informed and timely decisions based on the data and information provided by data-processing technologies helps to prove the research thesis.

- **Communication technologies** include devices and methods that facilitate the exchange of data and information between different actors and platforms, in particular, various sites and representatives of the livestock sector.

Point (1) of paragraph 1 concludes the balance between potential benefits and related challenges arising from digital transformation processes in the livestock sector.

Point 2 of Chapter One summarizes ***the main directions of the digital development of animal husbandry as a business***. They are:

- Animal identification system
- for quality traceability.
- for data management;
- for identification and traceability of production.
- for quality management and certificates.
- blockchain technology;
- Internet of Things;
- farm-to-fork strategy
- contribution to the Green Deal.

Paragraph 1(2) of Chapter One focuses on ***the identification of different species of animals, depending on the purpose and national characteristics of European countries.***

Precision is crucial for modern agriculture. The ability to identify and track productive animals in livestock populations is not just a matter of convenience, it is a critical component for optimizing efficiency, ensuring animal welfare, and improving business sustainability. Identification of productive animals is necessary for animal husbandry.

- **More precise control;**
- **Disease control and biosecurity;**
- **Genetic improvement;**
- **Traceability and quality assurance;**
- **Data-driven decision-making.**

A detailed **classification of the identification methods and systems** is summarized in Section 2.1. of Chapter One.

They can be mandatory, legally, and administratively necessary, business support systems (managerial identification).

Group identification is used by different types of animals for large ruminant (UPS) cattle, buffaloes; - small ruminants (UPS), sheep, goats, pigs, and bee colonies. For birds and fish, group identification is used.

Identification for managerial purposes can be an external and internal means of identification, a and passive and active means of identification.

It is also possible to use identification to achieve various additional purposes, such as collecting data on the physiological and health status of animals, tracking their geographic location, and controlling their movement.

Identification of animals according to their method of rearing: pasture, fully barn-keeping, combined rearing (barn and pasture).

The benefits of correct identification were analysed in terms of

- Traceability of the origin and quality of products;
- Improving the management of livestock farms;
- Fight against fraud and unfair competition.

The consequences of lack of identification include health risks and diseases, difficulties in tracking and controlling livestock operations; and economic losses due to insufficient quality of food and products.

A conclusion was formulated regarding the strategic importance, practical feasibility, and economic feasibility of the need for each farm to define and implement adequate methods for animal identification.

Paragraph 2, point 2 of Chapter One discusses ***the systems for traceability of the quality of production in livestock breeding and trends in the development of the process.***

Livestock farming is one of the sectors most affected by the farm-to-fork strategy, where measures are defined that affect the sector from different perspectives (environment, public health, and animal welfare).

The analysis includes:

- Evaluation and revision of EU animal welfare legislation, including legislation on the transport and slaughter of animals.
- Proposal for a revision of the Feed Additives Regulation to reduce the environmental impact of animal husbandry (particularly methane and nitrous oxide emissions);
- Specific actions aimed at agriculture:

The following are examined and evaluated in detail:

- Electronic Identification Systems (EID).
- Data management systems.
- Product identification and traceability systems.
- Quality Management and Certification Systems.
- Use of technologies such as blockchain and Internet of Things (IoT).

The "Farm to Fork Strategy “is analysed in detail as a complex system of technical solutions guaranteeing the awareness and security of the user. Various technical solutions have been formulated for individual processes.

- **Supply chain digitalization:**

- Sensors and RFID technologies embedded in food packaging;
- Web and mobile platforms for food shopping;
- Blockchain technologies to trace the origin of food products;
- Systems for assessing the sustainability of products;
- GS1 standards;
- RFID labelling.

It has been summarized that food traceability systems use various technologies and standards, such as Blockchain, GS1, and RFID, to ensure transparency, safety, and efficiency in the food supply chain. It is concluded that models and technological solutions (EID, blockchain, GS1/GTIN/QR/RFID) that provide transparency along the chain are the basis for quality assessment **from farm to fork**.

Paragraph 3(2) of Chapter One discusses innovation ***in livestock farming contributing to the green economy.***

In summary, innovations in farming businesses are necessary to preserve balance in natural ecosystems. The "green economy" implies a moderate use of resources in order for them to be successfully regenerated. The greenhouse effect and imbalance in raising animals for food can have a detrimental impact if investments are not made in innovations that can improve the overall process.

Point 2(3) examines ***environmental effects and the green economy***. Sources of emissions (including methane), solutions through selection, nutrition, automation, and circular economy (waste management and recovery) were outlined.

Point 3 of Chapter One discusses ***the general characteristics and possibilities for the development of automation in animal husbandry processes.***

"Opportunities for the development of automation in animal husbandry processes include the use of modern technologies such as sensors, monitoring systems, robotic devices and software platforms, which aim to improve the efficiency, quality and health of animals, as well as optimize production processes and resources." In general, they can be divided into: (Chernaev, 2023)

- Integration of monitoring sensors;
- Automated feeding systems;
- Automated Environmental Management Systems;
- Automated health-monitoring systems

- Robotic systems for performing various operations.

The advantages of digitalization of livestock breeding can be generally characterized by:

- Increased efficiency;
- Better control;
- Better health of animals;
- Cost reduction;
- Greater accuracy and quality of production.

In paragraph 1, point 3 of Chapter One, an ***assessment of Digital Transformation and Smart Animal Husbandry has been carried out***.

The results of the Intelligent Animal Husbandry (IJ) project are cited. Emphasis is placed on the possibilities for automation in the following types of activities: animal feeding; diagnosis and treatment; pasture management.

Some of the automation capabilities include:

- GPS and navigation systems for measuring, mapping and marking pasture boundaries;
- Automated irrigation systems;
- Electric herders and animal control systems;
- Monitoring and management of vegetation.
- **Synchronize fertilizations** via

- Automated synchronization protocols;
- Use of electronic monitoring systems;
- Use of systems for automatic measurement of hormonal levels;
- Automatic lighting control systems;
- Use of electronic monitoring systems for animal behaviour.

- **Production planning through**

- Inventory and resource management systems;
- Automated systems for forecasting production capacity;

- Automated systems for control of the breeding process;
- Use of analytical tools for decision-making;
- Integration of farm management systems.

➢ **Quantity and Quality Measurement and Control Systems**

As a result, the possibilities for process automation have been investigated and evaluated: microclimate monitoring, smart feeding/watering, health status and behaviour, milking/cleaning robots, telemedicine and AI diagnostics.

Paragraph 2, point 3 of Chapter One discusses ***digital technologies as an innovative approach in farming and the advantages of digitalization of agribusiness.***

The innovative approach that digital technologies provide to farm businesses is considered in several directions:

- Production process management;
- Improvement of management solutions;
- Increase efficiency and productivity;
- Improving marketing and sales;
- Sustainable agriculture.

An important conclusion has been made that digital technologies cannot be implemented in the same way "on a conveyor". Each farm is characterized by individual specifics, depending on different indicators and signs – an author's classification has been created.

Table 1.2. Types of farms by different characteristics

Sign	Type: Truss
By species of animals kept	Cows, Buffaloes – EPJ (Large ruminants);
	Sheep, goats – PWFs (small ruminants)
	Pigs.
By method of cultivation	Pasture;
	Oborn (Freestyle boxing or boxing);
	Mixed.
	Industrial animal husbandry;

By management structure of the farm	Farm of a zoo engineer or veterinarian;
	Family or hereditary farm.
Companies divided **by types of legal form of management**	Individuals;
	Sole proprietors;
	Cooperation;
	Companies
Differences **in farm size**	Small – up to 50 sheep, up to 15 cows;
	Average 50-400 sheep, 20-50 cows;
	Large/industrial over 450 sheep, over 60 cows.
By the type of production that has the highest priority for the company	For milk;
	For meat;
	For breeding.
By type of feeding (feed supply)	Own production;
	Purchase of feed.

Source: author's study

Since quality reproduction depends mostly on the qualities of the parents, not a small part of the farms concentrates on the creation of animals for breeding and sale at reproductive age.

The created classification, its approbation to specific companies and the reporting of the results proves the hypothesis that digitalization is conditioned by the size and profile of farms, breed and breeding technology; its dependence on managerial competences;

Paragraph 3(3) of Chapter One discusses the ***advantages and comparisons of process automation on farms.***

Based on the analysed methods, systems and processes, summary tables have been developed that present the advantages of automation in process management. In the tables, comparative assessments have been carried out in accordance with the scale of the holding. For the purposes of the analysis, a metric "Impact Scale on the Company" has been introduced, with estimated values from 1 to 10, with a value of 10 reflecting the highest degree of impact.

- **Animal Nutrition Process**

It is concluded that the use of automation of feeding processes is as important as possible for medium and large farms. A large part of the risks is reduced by the scale of large farms or by the higher motivation of the staff in small farms.

Table 1.3 – Advantages and comparison of manual and automated feeding

Advancements	Automation	Manual Feeding	Malka Farm Rock	Rock Medium Farm	Rock Big Farm
More accurate and consistent feeding	✓ Greater accuracy of nutritional doses	✗ Greater risk of malnutrition	**1**	**6**	**9**
Greater efficiency and time savings	✓ Need for fewer human resources	✗ Requires more time to serve food	**10**	**10**	**9**
Minimal food losses	✓ Minimal food losses	✗ More losses from improper nutrition	**6**	**10**	**10**
Better control and monitoring	✓ Better control and monitoring	✗ More limited control options	**6**	**9**	**10**
Lower operating costs	✓ Lower operating costs	✗ Higher operating costs	**1**	**8**	**10**

(*source: author's study*)

- **Process "Diagnosis and treatment"**

It has been proven that the processes of diagnosis and treatment demonstrate a high degree of dependence on automation, regardless of the scale of the farm (Table 1.4). There is a tendency of stronger impact in smaller farms, due to the possibility of shared use of veterinary resources and greater sensitivity to losses, which determines a higher motivation for the implementation of telemedicine and remote technologies.

Table 1.4 – Advantages and comparison of manual and automated diagnosis and treatment

Advancements	Automation	Manual diagnosis and treatment	Malka Farm Rock	Rock Medium Farm	Rock Big Farm
Faster and more accurate diagnosis process	✓ Faster and more accurate results	✗ Slower and less accurate diagnosis	**10**	**10**	**8**

More effective and individualized treatment	✓ Individual treatment adjustment	✗ More limited options for individualized treatment	**10**	**8**	**6**
Minimal risks of human error	✓ Less likelihood of human error	✗ Greater risk of human error	**10**	**9**	**8**
Better health monitoring	✓ More precise health monitoring	✗ More limited monitoring options	**10**	**9**	**8**
Lower operating costs	✓ Lower operating costs	✗ Higher operating costs	**10**	**9**	**8**

(*source: author's study*)

- **Pasture management process**

Automation in pasture management has several directions (Table 1.5). Construction of fences/electronic shepherd and the ability to manage individual paddock sections in order to optimally use the possibilities of nature and plan the grass stand are the main directions in which the theory and practical developments are developed.

Table 1.5 – Advantages and comparison of manual and automated pasture management

Advancements	Automation	Manual pasture management	Malka Farm Rock	Rock Medium Farm	Rock Big Farm
More efficient use of space	✓ Optimal use of pastures	✗ Greater likelihood of uneven area use	**3**	**6**	**8**
Better control over feed yield	✓ Better control over feed yield	✗ Less control over feed yield	**1**	**6**	**8**
Fewer risks of excessive trampling	✓ Fewer risks of excessive trampling	✗ Greater risks of excessive trampling	**1**	**8**	**6**
Lower operating costs	✓ Lower operating costs	✗ Higher operating costs	**1**	**8**	**6**

(*source: author's study*)

According to the Agrostatistical Surveys (Table 1.6, Table 1.7 and Fig. 1.2), the number of livestock farms in the country is decreasing at a very rapid pace due to the increase in the average number of animals on the farm. In other words, the trend is towards business consolidation. At the same time, the number of livestock establishments is relatively much smaller, according to the official registers of the BFSA.

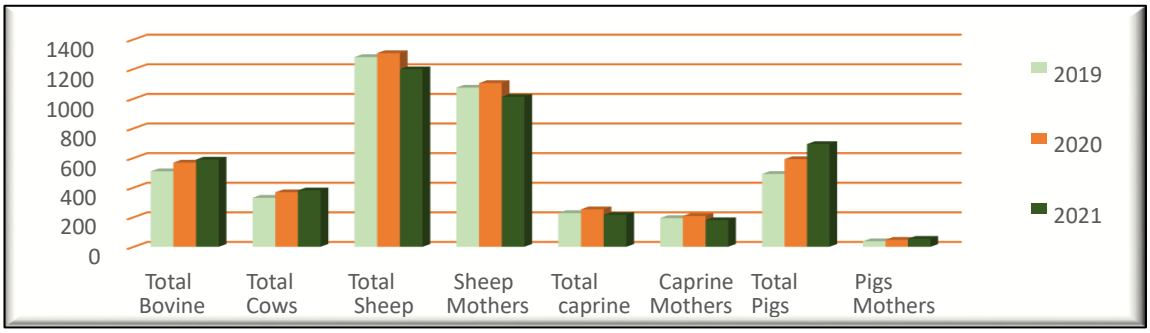

Figure 1.2 – Number of animals in Bulgaria (*source: Agrostatistics*)

Table 1.6 – Number of farms and animals in Bulgaria by species, categories and years

Таблица 3.1. Стопанства и отглежданите в тях селскостопански животни* по видове и категории
Table 3.1. Livestock breeding holdings and number of heads* by species and categories

Видове и категории животни	Стопанства Holdings				Животни Heads			
	2010	2013	2016	2020	2010	2013	2016	2020
Общо говеда	**95 357**	**69 564**	**54 376**	**31 425**	**576 339**	**576 280**	**584 177**	**612 122**
Крави (общо)	**86 210**	**63 101**	**48 714**	**28 612**	**347 291**	**348 282**	**365 975**	**391 981**
в т.ч. млечни крави	85 454	61 173	39 603	19 738	327 462	308 516	276 923	**237 159**
в т.ч. други крави	1 113	2 993	9 932	9 955	19 829	39 766	89 052	**154 822**
Юници на 2 години и повече	5 355	2 887	2 199	2 096	24 719	13 805	17 191	**14 230**
Мъжки говеда на 2 години и повече	2 624	3 019	2 414	2 914	6 456	5 340	5 756	10 287
Юници от 1 до 2 години	11 008	8 823	7 906	6 365	39 025	49 127	51 308	51 005
Мъжки говеда от 1 до 2 години	6 064	3 654	3 483	6 654	17 381	12 303	16 180	35 139
Телета под 1 година	48 076	43 382	28 515	16 579	141 467	147 423	127 767	109 480
Общо биволи	**1 028**	**648**	**545**	**654**	**10 038**	**9 962**	**13 762**	**22 027**
Биволици	817	467	390	459	6 323	6 154	8 428	14 577
Малакини на 1 година и повече	246	170	188	232	984	1 198	2 224	3 004
Мъжки животни на 1 година и повече	238	163	197	286	636	629	922	1 455
Малачета под 1 година	449	338	287	328	2 095	1 981	2 188	2 991
Общо еднокопитни	**92 806**	**48 783**	**23 160**	**9 437**	**112 632**	**62 541**	**42 328**	**30 138**
Общо кози	**84 582**	**45 416**	**26 744**	**11 951**	**388 866**	**285 619**	**267 652**	**246 580**
Кози майки и млади женски кози за разплод	84 121	44 945	26 688	11 867	344 302	261 893	234 615	220 352
Други кози	14 391	8 798	7 550	5 031	44 564	23 726	33 037	26 228
Общо овце	**91 793**	**57 201**	**39 094**	**22 350**	**1 415 181**	**1 353 086**	**1 317 323**	**1 290 314**
Овце майки и млади женски овце за разплод	91 133	56 494	38 759	22 086	1 272 477	1 244 414	1 179 226	1 164 948
Други овце	19 999	17 875	17 808	12 244	142 704	108 672	138 097	125 366
Общо свине	**82 265**	**50 104**	**30 143**	**3 367**	**670 469**	**573 633**	**668 013**	**641 978**
Женски свине за разплод	15 235	4 831	3 349	612	73 547	55 414	62 637	65 924
Прасенца до 20 кг	3 963	2 167	969	330	140 881	100 040	116 057	180 586
Други свине	75 478	48 106	28 583	3 011	456 041	418 179	489 319	395 468

(*source: Agrostatistics*)

Table 1.7 – Number of farms and animals in Bulgaria

Number of farms and animals in Bulgaria as of November 1, 2021										
Indicators	**Cattle total**	**Cows in total**	**Buffaloes in total**	**Buffaloes**	**Pigs in total**	**Pork T-shirts**	**Sheep total**	**Sheep T-shirts**	**Goats in total**	**Kozi T-shirts**
Animals (thousands)	589.5	381.4	21.6	15.4	694.7	54.3	1 199.5	1013.2	215.0	179.8
Change 2021/2020	3.7%	3.8%	6.9%	9.2%	17.3%	16.8%	-8.3%	-8.4%	-15.2%	-13.4%
Farms (thousand units)	25.5	24.0	0.6	0.5	1.5	0.3	19.3	18.9	9.2	9.1
Change 2021/2020	-9.9%	-8.0%	0%	0%	-28.6%	-25.0%	-2.0%	-3.1%	-10.7%	-10.8%
Average number of animals per farm	23.1	15.9	36.0	30.8	463.1	181.0	62.2	53.6	23.4	19.8
Change 2021/2020	15.0%	12.9%	6.9%	9.2%	64.3%	55.7%	-6.4%	-5.5%	-5.0%	-3.0%

(*source: Agrostatistics*)

The "virtual animals" syndrome is caused by the lack of consistency in the data of the State and the farms and is noticeable when comparing the data. There is also a high degree of influence due to the uneven concentration by region, respectively the lack of sufficient areas for natural pastures. This fact has a detrimental effect on the development of the livestock sector.

- **Process "Synchronization of fertilizations"**

Table 1.10 – Advantages and comparison of manual and automated fertilization synchronization

Advancements	Automated synchronization	Manual synchronization	Beef sheep	Milky sheep	Meat Cows
Greater accuracy of fertilization time	✓ More accurate determination of the fertilization period	✗ Greater likelihood of errors in determining the fertilization period	**10**	**10**	**10**
Higher probability of success in fertilization	✓ Higher probability of successful fertilizations	✗ Lower probability of successful fertilizations	**8**	**9**	**10**
More efficient use of genetic resources	✓ Better management of genetic potential	✗ More limited management options	**6**	**6**	**10**
Lower operating costs	✓ Lower operating costs	✗ Higher operating costs	**1**	**1**	**8**

(*source: author's study*)

- **Production planning process**

The results show that production planning systems are mainly implemented in large farms, where strategic management is closely linked to a high degree of automation and advanced control mechanisms (Table 1.11). However,

profitability remains highly dependent on external and difficult to predict factors, which calls into question the effectiveness of large-scale expansion as a universal strategy for increasing profits.

Table 1.11 – Advantages and comparison of manual and automated production planning

Advancements	Automated scheduling	Manual planning	Koef. Small Farm	Koef. Medium farm	Koef. Big Farm
Greater accuracy of production forecasts	✓ More accurate production forecasts	✗ Less accurate production forecasts	**1**	**7**	**10**
More efficient use of resources	✓ Better use of manpower, raw materials and equipment	✗ Reduced resource utilization	**1**	**10**	**10**
Reduced losses from non-sales products	✓ Less losses from non-sales products	✗ Greater losses from non-sales products	**3**	**10**	**10**
Lower operating costs	✓ Lower operating costs	✗ Higher operating costs	**10**	**10**	**10**

(*source: author's study*)

Conclusions from Chapter One

1. From the theoretical review, it is clear that digitalization is an important need in the modern livestock farm. The future development of digitalization as a process is an integral part of livestock management. For this purpose, knowledge, skills and competencies in the field of digital technologies are needed.

2. Choosing a winning strategy for digitization of each particular company depends on many factors, and the mechanical transfer of a business model from one farm to another is not always the most cost-effective. For a large part of the digitalization options considered, the analysis shows that separately it would be most cost-effective to manage a large dairy cattle farm if there are sufficient resources for the initial investment and its maintenance. This could also be the riskiest investment.

3. In the meat sector (both cows and sheep) – the scale increase (the expansion of the farm) depends a lot on the stages of the agri-food chain that the company covers. It is common here that it is more correct to start the design of the farm

from the market through resources such as "pastures", "qualification of the workforce" in order to minimize the risks. According to the analysis, medium-sized farms are the most profitable here. In the event that a family farm with a zoo engineer or veterinarian is considered between the owners/managers of the farms, the development of the company depends on the market of the final product, not on technology and digitalization.

4. Building the digital strategy of the "ideal farm" depends on all of the above factors and should be planned and evaluated in advance, according to all criteria and attention should be paid to the complexity of the assessment.

5. In order to build and optimize the business model of "The Ideal Farm “, a **digital strategy** should be created for each specific company with evaluation criteria dictated both from an economic point of view and corresponding to the company's vision and the competence of the staff.

CHAPTER TWO
DIGITALIZATION OF LIVESTOCK FARMS – CHALLENGES AND OPPORTUNITIES

Point 1 of Chapter Two discusses ***the classification of processes and technical solutions depending on the type of animals and their way of keeping.***

The management of a livestock farm can be fully digitized through integrated automated systems that optimize work processes, control and traceability, regardless of the scale and structure of the farm.

Paragraph 1(1) of Chapter Two discusses the ***process of Automated Feeding***. It is carried out with systems that automatically distribute feed based on preset schedules and quantities.

The classification of digital animal nutrition management systems encompasses various approaches that use technology to improve livestock nutrition management. These systems can be broadly categorized based on their

operational principles, technological integration and the specific animal species they target (Table 2.1).

Table 2.1 - Automated Feeding Process

	GROUP	Individual
By purpose	For fattening	For control and better selection
Funds used	Dosing system, "feed kitchen" stationary, mixing trailer, transport feed belts	Dosing systems complete with identification
Means of carrying out the process	Management and reporting systems, scales in silos, scales in trailers, Cameras according to a predefined scheme for the group	Identification system complete with a dosing system, usually according to a pre-set prescription depending on the physiological state of the animal
Means of exercising control over the result	Group/selective withdrawal. Control over the cost of income	The result is assumed to be equal to the planned one, since this decision does not imply human intervention
Influence on another process	Herd management; Control over the stock of resources; Direct cost of production, since over 70% of the cost is formed by food	
It is used in	All animals designated for meat production; Specific to growing lambs/calves after weaning and milk replacer. When feeding with concentrated feed of all animals, depending on the specific physiological condition.	Sows are kept in individual pens for most of their life cycle, and this system guarantees a high increase in the number of animals. The system is also used in cows, but on a much more limited scale, mainly for scientific and breeding purposes.

(source: author's study)

The conclusion of this paragraph is that the classification of digital animal nutrition management systems reveals a diverse landscape of technological applications aimed at improving animal health, welfare and production efficiency. The integration of digital technologies, precise feeding strategies and sustainable practices is essential for progress in the field of animal nutrition management.

In paragraph 2, point 1 of Chapter Two, the ***process of Health Monitoring is examined***. It is carried out through a combination of sensors (located on or in animals) that track various health indicators (such as temperature, activity, experience) and software applications processing the data.

The takeaway from this paragraph is that IoT solutions for monitoring animal health offer significant benefits for farmers, including improving animal health, optimizing production processes, and reducing costs. However, the successful implementation of these technologies requires careful planning, cost estimation, and staff training. With the right approach, IoT can transform animal husbandry and provide a sustainable future for the sector.

Paragraph 3, point 1 of Chapter Two discusses ***the process Milking - Milking Robots*.** The path of milk to the end customer goes through several stages, from milking the animal, through temporary storage and transport to processing and creation of the final product and systems for reporting and quality control at various points.

Milking systems in animal husbandry range from manual to fully robotic solutions, and the degree of automation is directly related to the possibilities for individual measurement, identification and integration with health monitoring systems, which increases the efficiency and quality of production.

Table 2.2. Analysis of livestock farms in Bulgaria: Regional structure and use of technologies

Region	Type of animals	Total number of farms	Percentage of farms with milking parlors	% of farms using software
Northwestern	Cows	150	50%	30%
	Sheep	200	25%	15%
	Buffalo	30	60%	40%
	Caprine	50	20%	10%
North Central	Cows	200	55%	35%
	Sheep	300	30%	20%
	Buffalo	50	50%	30%
	Caprine	80	25%	15%
South Central	Cows	180	65%	40%
	Sheep	350	35%	25%
	Buffalo	40	70%	50%
	Caprine	60	30%	20%
Southwest	Cows	250	60%	45%

	Sheep	150	40%	25%
	Buffalo	20	80%	60%
	Caprine	70	35%	15%

(source: Agrostatistics)

The conclusion of this paragraph is that the digitalisation of the milking process offers multiple opportunities to increase productivity, sustainability and animal welfare in dairy production. The integration of IoT, AI, and automation technologies can transform traditional practices, allowing farmers to respond more effectively to the challenges posed by a growing global population and growing demand for dairy products. However, it is crucial to address the socio-ethical implications of these advances and ensure that all farmers have access to the tools and training. necessary for prosperity in a digital agricultural environment.

Paragraph 4, point 1 of Chapter Two *discusses* ***the process of Environmental Control***. These are automated systems for controlling the temperature, humidity and ventilation of the barn.

The effective management of the microclimate through automated systems for control of temperature, humidity and ventilation is essential for the welfare, productivity and energy efficiency in dairy production.

The bottom line is that effective microclimate management is vital for dairy cow welfare and the sustainability of cow farms. By optimising environmental conditions, farmers can improve milk production, reduce energy costs and improve the overall health of their livestock. caused by climate change, and to ensure the long-term viability of dairy production.

Paragraph 5, point 1 of Chapter Two discusses ***the manure management process***, which is carried out through automated manure collection and disposal systems, which are based on sensors and software, improve resource efficiency, reduce costs and emissions, and contribute to sustainable agriculture through optimized nutrient application

The conclusion is that manure management through automation is an important aspect of modern animal husbandry. The implementation of automated systems not only optimizes processes, but also improves the profitability of the sector. By reducing costs, increasing productivity and improving production quality, automation plays a key role in the sustainable development of animal husbandry.

Paragraph 6, point 1 of Chapter Two discusses ***the process of Grazing Management***. The digitalization of this process is carried out through GPS and IoT-based systems for managing grazing patterns and pasture rotation.

The grazing management process is digitized through GPS, IoT and GIS technologies that allow real-time tracking of animals, spatial data analysis and optimization of pasture rotation. The integration of electric herders and virtual fences contributes to sustainable use of resources, reducing environmental risks and improving animal welfare, and these technologies are establishing themselves as a key tool for modern and ecological animal husbandry.

The conclusion of this paragraph is that GIS solutions, GPS technologies and electric shepherds represent important grazing management tools that offer new opportunities for sustainable resource management. By integrating these technologies, farmers can improve the efficiency of their practices, minimize negative environmental impacts and ensure better animal welfare. in different contexts, it will be essential for the sustainable management of agricultural systems.

Paragraph 7(1) of Chapter Two discusses ***the process of monitoring reproduction***.

The digitalization of the reproductive management process through sensors, GPS, RFID and biotechnology allows tracking of physiological conditions and behaviour in real time, improves reproductive efficiency and contributes to the sustainability of livestock farming, while requiring overcoming challenges related to access to technology and training of farmers.

In conclusion, it is concluded that the digitalization of reproductive monitoring processes in animal husbandry is a transformative development that promises to increase productivity, sustainability and animal welfare. By integrating advanced technologies and biotechnological innovations, farmers can optimize reproductive management, reduce environmental impact and improve economic performance. technology adoption and ensuring equitable access to these innovations will be crucial to realise the full potential of digitalisation in livestock reproduction.

Paragraph 8(1) of Chapter Two discusses ***the process of herd management***. This process includes planning, reporting and control of all processes in the livestock business, cost and profitability analysis.

Herd management is an integrated system combining key processes such as health monitoring, feeding, milking, reproduction and realization, for the purpose of effective planning and control. Practical research shows that the use of unrelated software applications leads to fragmented management, inaccurate cost and lack of traceability.

The implementation of integrated digital solutions, combined with hardware devices (milk meters, scales, identification readers) and regulatory identification, is essential for precise control, selection efficiency and economic sustainability.

The digitalization of the process from the birth of the animal reduces selection errors and increases the accuracy of cost allocation, which leads to better strategic management and increased economic value of biological assets.

An important condition for the digitization of any process related to herd management is the need for digitization of animal identification.

Point 2 of Chapter Two examines ***the possibilities and problems of the different animal identification systems*.**

Paragraph 1(2) discusses ***the types of READERS, distinguished by functionality.***

➢ **MEMORY READER** varying between 2000-20000 identification tags. The technology of working with this class of readers is "offline", with limited functionality and the possibility of duplicate records, i.e. it is not a reliable counter.

➢ **INFORMATION SYSTEM READER-DISPLAY**. It is an online reader transmitting the data directly to the "cloud". From the server, the information is visualized in the appropriate form on a phone, tablet, computer, where the "dossier" of the specific animal or guidelines for the envisaged action for this animal is received.

➢ **INTERACTIVE SYSTEM READER – SOFTWARE** is a system for visualization of the file of the specific animal and the possibility of individual recording of the information from the actions carried out back into the system. It is a fully functioning online/offline system. Its characteristic is that it contains pre-prepared lists and allows for comparison of the data in real time. Animal. The two-way connection makes it possible to initiate additional actions by the operator – creating temporary lists, reflecting unplanned actions and correcting the data (retagging) of specific animals.

➢ On the basis of the interactive reader-software system, during the preparation of the dissertation, a prototype of the *System* ***"Artificial Intelligence in Aid of Sheep Reproduction“ was created.*** The "AI for Reproduction" system aims to create the most appropriate "case plan" for each animal, and the decision is made on the basis of avoiding embryonisation and combining the best productive indicators for the breed based on historical data for each animal and/or its parents. This project for the development of innovation, inspired by the dissertation, caused a technical revolution and directed the breeding activity in a qualitatively new direction.

Paragraph 2(1) of Chapter Two discusses ***the types of ear tag READERS, differentiated by user.***

- **User FARMER.**
- **User VETERINARIAN**
- **User BREEDER / ZOOENGINEER**

The analysis of various designs and technical parameters of the readers is done in order to determine the most appropriate one for use for each specific process and user. The classification derived from practice allows for a realistic view of the development of the digital transformation process in all subjects involved in it.

Animal identification systems are a fundamental component in the digital management of the livestock business, with readers distinguished by frequency, type and functionality. The standard frequency of 134.2 kHz, according to ISO 11784/11785, is mandatory for small ruminants (UPS) in the EU, but has a limited reading range, making automation difficult in larger animals or in pasture conditions. For managerial purposes, additional technologies such as HDX and 868 MHz are also used, which allow remote reading and greater operational efficiency. The readers are classified as manual, stationary and combined, and in terms of functionality – from basic memory devices to interactive systems with two-way connection and integration with herd management software.

In the context of business management, ERP systems for animal husbandry should build on standard modules with functionalities specific to biological assets – such as identification, health monitoring, productivity and selection. This necessitates adaptation of classical ERP philosophies, since production (e.g. milk) is a variable value, and the cost depends on many biological and environmental factors. Specialized solutions such as Herdwatch, AgriWebb, Uniform-Agri, as well as the Bulgarian FermaWeb and Agrosystems, demonstrate the possibilities for integrated management – from the feed mill to the final product.

Integration between hardware devices, software platforms and state registers (e.g. VetIs, SEU, NRA) is critical to achieving full traceability, data accuracy and sustainable management. ERP systems can support not only cost-effectiveness, but also environmental monitoring by providing tools for resource analysis and environmental impact management. Research shows that digitalization in animal husbandry leads to improved animal health, faster response to diseases and better herd welfare.

In conclusion, livestock management ERP systems offer numerous benefits, including improved productivity, resource management, animal health monitoring, and optimization of financial processes. By integrating various aspects of management, ERP systems can help farmers respond to the challenges of the modern livestock industry and ensure the sustainable development of the sector.

Point 2 of Chapter Two ***presents a theoretical economic model for the management of the "Ideal Livestock Farm"***

Paragraph 1, point 2 discusses ***the model "The ideal farm" depending on the participants – veterinarian, breeder, farmer***

- **The point of view of the VETERINARIAN:**

The need for identification of animals in their treatment, deworming, immunoprophylaxis, examination of the condition, sampling of the general condition of the particular animal and the herd as a whole.

- **The point of view of the BREEDER / ZOOENGINEER**
- **The FARMER's point of view**

From the farmer's point of view, all the analysed opportunities for digitalization are important, but apart from them, he is the main source of solutions for managing his business in order to achieve the best possible economic realization. Therefore, the model of the "ideal farm" includes digital solutions that

are rational in terms of increasing the quantity and quality of production and reducing the cost.

In general, the processes on the farm that are discussed in this work can be classified on the basis of: the types of animals that are kept (cows, buffaloes; sheep, goats; pigs...); the method of cultivation (pasture, barn, mixed); the management structure of the farm in terms of business ownership and qualification of the operational and managerial personnel.

Most conventionally, they can be divided into two groups – industrial livestock breeding and family and/or hereditary farms or those owned by veterinarians or zoo engineers.

- **Family farms.** For them, digitalization depends on the work of the veterinarian and the zoo engineer (association).
- **Farms based on the education of the owner/manager.** They are characterized by the fact that they are the most innovative, looking for practical solutions to increase their real efficiency and competitiveness in the market.
- **Companies with an established management structure, usually owned by another business (investor),** holding organizations that prefer more serious investments in "industrial animal husbandry". Often these farms are built by investors to close the production cycle. They can be: owners of dairies/slaughterhouses; grain producers or investors from other industries.

Especially important for increasing the economic profitability of the farm is which **processes will be digitized and how the connection between them will be made**. Most farmers have automated a large part of the processes, but planning and reporting often remain in the "background". In order to calculate the correct cost and economic profitability, it is necessary to digitize all processes - feeding, depending on the type of farm, only part of the processes can be digitized or only some physiological conditions can be tracked in more detail.

Paragraph 2(2) of Chapter Two provides ***an analysis of investments in the theoretical model.***

The following methodology has been adopted to assess the investment costs of implementing digital process solutions. It is assumed that for each type of process (group of processes) one of the possible suppliers and an average cost value are evaluated. In the analysis, it was accepted that each solution should be evaluated independently, without looking for complexity and reduction of investments of scale. This methodology allows the model to be applied to companies of different sizes and ways of management.

In Table. 2.3 The automated processes and their costs are indicated.

Table 2.3 – Table of automated processes and costs.
In the table, an estimate is made for approximately 150 cows

Case	**Description**	**Initial investment costs (EUR)**	**Fixed costs** (Euro per year)	**Price per animal** (Euro per year, excluding initial)
Automated feeding	Systems that automatically distribute feed based on preset schedules and quantities	133 000	9 600	64
Health Monitoring (DeLeval)	Wearable sensors - to track health indicators such as temperature, activity and experience	69 000	12 400	69
Milking robots (Lely.com)	Automated milking systems for dairy cows	240 000	24 900	166
Environmental control (CowAir.com)	Automated systems for control of temperature, humidity and ventilation of the barn	21 300	1 950	13
Manure management (Patura.com)	Automated manure collection and disposal systems	51 000	3 240	18
Grazing management (Feedlync.eu)	GPS and IoT-based systems to manage grazing patterns and pasture rotation	31 500	10 800	72
Reproduction monitoring (Cowealthy/ WiCow.io)	Estrus cycle tracking systems and optimizing breeding schedules	23 000	2 560	17

Security Systems	Surveillance cameras and automated gates for farm security	12 400	2 500	10

(source: author's study)

Paragraph 3, point 2 of Chapter Two discusses ***digitalization in pasture management*** through the application of modern technologies such as drones, sensors, geographic information systems (GIS), artificial intelligence (AI), machine learning and IoT. imprint. The need for integrated digital platforms to support farmers in the decision-making process was emphasized, as well as the need for further research on the socio-economic effects of the implementation of these technologies in agricultural communities.

Paragraph 4, point 2 of Chapter Two discusses ***digitalization in the processing of animal products - slaughterhouses, meat processing plants, dairies*** *(batches, labeling).* A systematization of the possibilities for digitalization of processes in the processing of animal products – in slaughterhouses, meat processing plants and dairies – as part of the "farm-to-fork" chain has been developed. Within the framework of the analysis, the key processes subject to automation have been identified, including: animal entry and traceability, kneeling, cutting, by-product management, process maps, batch management, labeling, stocks and administrative and commercial activities. The need for integration between hardware devices (electronic scales, readers, RFID and barcode systems) and software solutions to achieve traceability, reduce losses and increase efficiency is justified. A model for digitization of the slaughterhouse and dairy has been proposed, which requires minimal investment in equipment, but provides significant benefits through automated collection and analysis of data related to production and its cost.

Paragraph 5, point 2 of Chapter Two discusses ***the human factor in animal husbandry in robotics and automation of technological operations.***

The analysis shows that despite the significant advantages of digitalization and automation for increasing efficiency, sustainability and precise resource management, their implementation leads to significant social transformations in rural areas. The lack of digital culture, infrastructure and skilled personnel makes it difficult to actually implement technology, especially in vulnerable communities. The high degree of automation changes the labour structure and requires new knowledge and skills, which creates a risk of social exclusion. To ensure sustainable development of the agricultural sector and feed the population by 2050, strategic planning, investment in training and policies to support affected communities are needed, especially in the context of the uptake of artificial intelligence

Paragraph 6(2) of Chapter Two discusses ***the incentives and challenges for the digitalisation of farms in the CAP.*** The principle of payment of subsidies is analysed and to what extent this depends on the systems for identification of animals and, respectively, on the level of digitalization of farms and control bodies.

Within the framework of the dissertation, the case with the so-called. "Virtual sheep" – a practice in which non-existent animals are declared in order to illegally receive subsidies. It has been found that the main prerequisites for this are the lack of real-time digitalization, the use of offline identification technologies, poor integration between the information systems of the BFSA, RVL and breeding organizations, as well as a blurred responsibility between the participants in the process. Calculations show that with a 10% deviation from the real number of sheep, the state budget suffers losses of more than 9.1 million leva. Lv. per year from direct payments, subsidies for pastures and paid veterinary manipulations. In response to this problem, specific technological and regulatory solutions have been proposed, including: introduction of automated identification

through IoT devices, construction of software gateways for direct connection with VetIs, integration of RVL systems and breeding associations, as well as the use of algorithms for automatic risk analysis through artificial intelligence.

At the end of point 2, the following conclusions are formulated:

The process of digitalization of animal husbandry is part of the future of humanity. Food and its production are part of the natural needs that we must comply with. The growing need for greater production of quality animal welfare food implies the introduction of innovations in business at a rapid pace. The digitalization and automation of livestock farming represent important factors for the future of rural areas. They bring both opportunities and challenges for social and economic development. To maximise benefits and minimize risks, strategic planning and support from governments and communities is needed. With joint efforts, rural areas can overcome challenges and make the most of technological innovations in animal husbandry.

Despite the positive aspects, digitalization and automation also pose challenges to rural areas. The need for significant investment in new technologies and workforce training can be a barrier for small and medium-sized enterprises. In addition, there is a risk of social exclusion of those who cannot adapt to the new working conditions.

The possibility of reducing jobs, and hence the standard of living in small municipalities, leads to an increase in the deficit of quality labour. Migration and demographic collapse only highlight such a possibility. Only with the help of science, meetings and forums are able to change possible negative trends and turn the trend into a positive one.

The role of the State in accelerating the digitalization process is key. Due to errors in the subsidy model, which are corrected with the help of inefficient information systems and mixing the tasks of control and operational work at the level of centralized (state systems), the focus of digitalization is shifted to process administration. This fact adds an additional administrative burden and greatly

lowers the motivation of farmers to implement innovative solutions. Tolerating the erroneous economic model, of subsidizing the number of registered animals, without linking to the actual existing and harvested production, even implies a decrease in interest in the implementation of digital technologies for development, redirecting the efforts of farmers to the need for systems for manipulating data and generating unreal reports. Regardless of the "sad experience of Greece" – the phenomenon of "virtual animals" is tolerated at the level of state government.

Building a theoretical model of the "Ideal Farm" involves refining technological solutions and finding a balance between the increasing needs for the quantity of quality food, profitability of the business and animal welfare. A balance could be achieved between industrialization and pastoral animal husbandry that does not greatly damage the environment and at the same time reaps all the benefits of digitalization. Creating such a model that satisfies all criteria is possible only if it is based on digital technologies that do not violate socio-economic relations and principles.

TRETA CHAPTER
DIGITAL SOLUTIONS FOR SMART ANIMAL HUSBANDRY IN THE REPUBLIC OF BULGARIA

Chapter Three presents the principal structure of the participants and the information systems involved in the process of digitization of the farm. The roles of the farm, veterinarians, breeders, accountants and state platforms such as VETIS, EASRJ and the e-portal of the National Revenue Agency (NRA) are examined. The study is based on the ERP system "FermaWeb" and its interaction with hardware solutions for identification, drawing and climate control, as well as ERP "Agrosystems" for tracking the food chain. The implementation of these systems to varying degrees allows for an analysis of the state of digitalization in livestock farms. The study is limited to the processes of herd management and the realization of production – meat and raw milk.

Point 1 of Chapter Three presents ***the Methodology of the survey*** conducted in the period 2022-2024, which includes field visits to more than 100 farms in Bulgaria and 10 abroad, as well as data collection through interviews, discussions and participation in scientific events. Analytical, comparative and statistical methods are used. 45 farms with different profiles were examined, and the study covers the entire production process - from the cultivation technology to the realization of production.

In point 2 of Chapter Three***, an analysis of the participants in the process of digitalization of the livestock business*** *is made.* These are: farms, RVLs, breeders, equipment traders.

The study reveals differences in attitudes and perceptions towards digitalization depending on the hierarchical level of the participants in the farms.

The main challenges include a lack of competence to work with technology, complexity of the solutions offered and the absence of a comprehensive implementation strategy. In over 70% of farms, digitalization is carried out in fragments, without sufficient training and integration between systems. Only half of the farms are ready to invest in upskilling.

The analysis shows that although Bulgarian farms lag behind in terms of actually implemented innovations, the challenges they face are similar to those in other EU countries.

Point 3 of Chapter Three discusses ***the digitalization of livestock farm management processes.***

The results of the study on the possibilities for digitalization in livestock breeding are distributed and described by livestock farm management processes (Fig. 3.1).

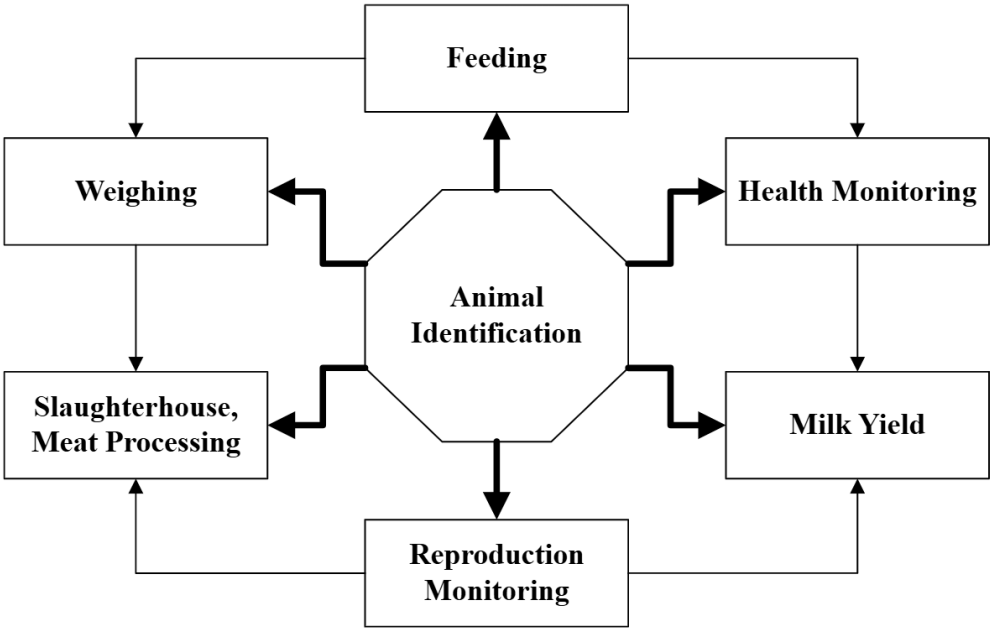

Figure 3.1 - Map of the processes in the management of a livestock farm (*source: author's study*)

According to Dr. **Georgi Yordanov** - Executive Director of the Executive Agency for Selection and Reproduction in Animal Husbandry (EASRJ) "Without identification of animals, there is no selection". This coincides with the author's thesis that the basis of digitalization in herd management is the identification of each specific animal. The analysis confirmed that the processes are interconnected and the presence or absence of digitalization of a process can bring benefits or shortages of information and taking into account other processes.

Paragraph 1(3) of Chapter Three deals with ***the process of 'Identification of animals'.***

The paragraph analyses the state of digitization of the "Animal Identification" process in 45 farms. The results show that while many farms possess electronic identification equipment, its actual use is limited and rarely associated with management systems. The implementation of FermaWeb improves the process through automation and synchronization of data in real time.

Table 3.2. Digitalization of the "Animal Identification" process – distribution by number of farms

	Sheep	**Caprine**	**Cows**	**Buffalo**
Total number of farms	**36**	**3**	**12**	**1**

Digitization of the number of farms	**20**	**1**	**8**	**0**
Digitalization is actually used in number of farms	**6**	**1**	**1**	**0**
The relevant process is related to the herd management system in cash farms	**1**	**1**	**1**	**0**

(*source: author's study*)

Paragraph 2, point 3 of Chapter Three examines ***the process of "Animal Towing"*** in 45 farms, with a focus on the use of electronic scales and their connection with herd management systems. The results show that although digitalization is present and actually used in 33 farms, only in 9 of them the process is related to a management system, The best integration is observed in pig breeding. The result is presented in a tabular way

Paragraph 3, point 3 of Chapter Three discusses ***the process of "Feeding automation"*** and pasture animal husbandry. The results, presented in tabular, show that electric shepherds are used in all cattle farms, and GPS tracking is used in half of them. Virtual shepherds have not yet been implemented. Over 50% of farmers prepare their own feed, resulting in improved feed conversion – by up to 12% in cows and 7% in sheep.

Table 3.4. Distribution by type of pasture support technology

Fermi	**Sheep/goats**		**Bovine animals**	
	Pc. Farms	**%**	**Pc. Farms**	**%**
Total number of examined	**3**		**12**	
Electric Shepherd	**1**	**33 %**	**12**	**100 %**
GPS tracking	**1**	**33 %**	**6**	**50 %**
Virtual Shepherds	**0**	**0 %**	**0**	**0 %**

(*source: author's study*)

Paragraph 4(3) of Chapter Three deals with ***the process of 'Health Monitoring'.*** of animals through external devices and IoT technologies. Portable laboratories for somatic cells and milking parlors with individual milk tracking have been studied, and implementation is limited due to technical and personnel difficulties. IoT devices such as rumen and vaginal boluses, which transmit biometric data in real time, have been tested. The vaginal bolus shows over 92% success rate in detecting oestrus, but the technology has not yet been implemented in Bulgaria. The results highlight the potential of digitalization to improve health control, but also the need to adapt to local conditions.

Paragraph 5, point 3 of Chapter Three discusses ***the process of "Automating milking"*** in sheep and cows, with an emphasis on efficiency, resources required and the degree of digitalization. Different types of milking parlors have been studied in sheep, and the results show a low degree of digitalization and a lack of individual reporting of milk, which limits the possibilities for management. In cows, automation is more developed, with the introduction of a milking robot (Lely) in one of the farms demonstrating significant benefits - improved health control, increased milk quality and reduced human labour. Data on time, operators and investments are presented in a tabular manner, highlighting the potential of digitalization to increase profitability, especially with the availability of appropriate human resources.

Paragraph 6(3) of Chapter Three deals with ***processes in slaughterhouses and meat processing.*** The digitalization of animal processing processes as part of the "field to fork" cycle is analysed. Five farms with their own slaughterhouses, three of which also have meat processing plants, are examined. Digitalization covers equipment, traceability systems, inventory management and orders. Only one of the companies works with a fully integrated system, while the rest use partial solutions. which leads to organizational difficulties. The lack of connectivity between departments can lead to serious losses, as shown in a specific case with a failed campaign and loss of a customer. The results highlight the importance of integrated digitalization for effective planning and management of the production cycle.

Paragraph 7, point 3 of Chapter Three discusses the ***process of Artificial Intelligence in the management of reproduction in animal husbandry. Creation of a "Case Plan".***

One of the main contributions of the dissertation is presented – the development of an innovative system for managing reproduction using artificial intelligence (AI). The system supports selection activities through automated prevention of embryonisation, intelligent selection of genetic combinations, synchronization of oestrus and remote collection of biometric data. The study shows that the use of AI in this process leads to significant economic benefits – improved productivity, reduced treatment costs and better management of food resources. This contributes to increasing the efficiency and competitiveness of livestock farms.

Point 4 of Chapter Three discusses ***the challenges in implementing digital solutions in the livestock sector*.**

The limitations of financing digital solutions in animal husbandry are analysed, and a subsidy model based on proven economic benefit is proposed.

Among the main contributions is the development of a system for evaluating innovations by comparing theoretical and real effect after implementation.

Paragraph 2(4) of Chapter Three deals with the problem of ***lack of motivation and qualification of staff.***

The reasons for low motivation and lack of qualification are investigated, and an approach to building an individual plan for the implementation of digitalization in each farm is proposed. The contribution of automation and AI to overcoming staffing challenges is highlighted, as well as the need for a link between education, science and business.

Paragraph 3(4) of Chapter Three deals with ***State control and assistance.***

The weaknesses in the VetIs system of the BFSA are analysed and a model for effective interaction between the farm management systems and the state platform is proposed. Among the main contributions is the development of an interface (API) and modules for automated data submission and synchronization, which reduce the administrative burden and increase the accuracy of information.

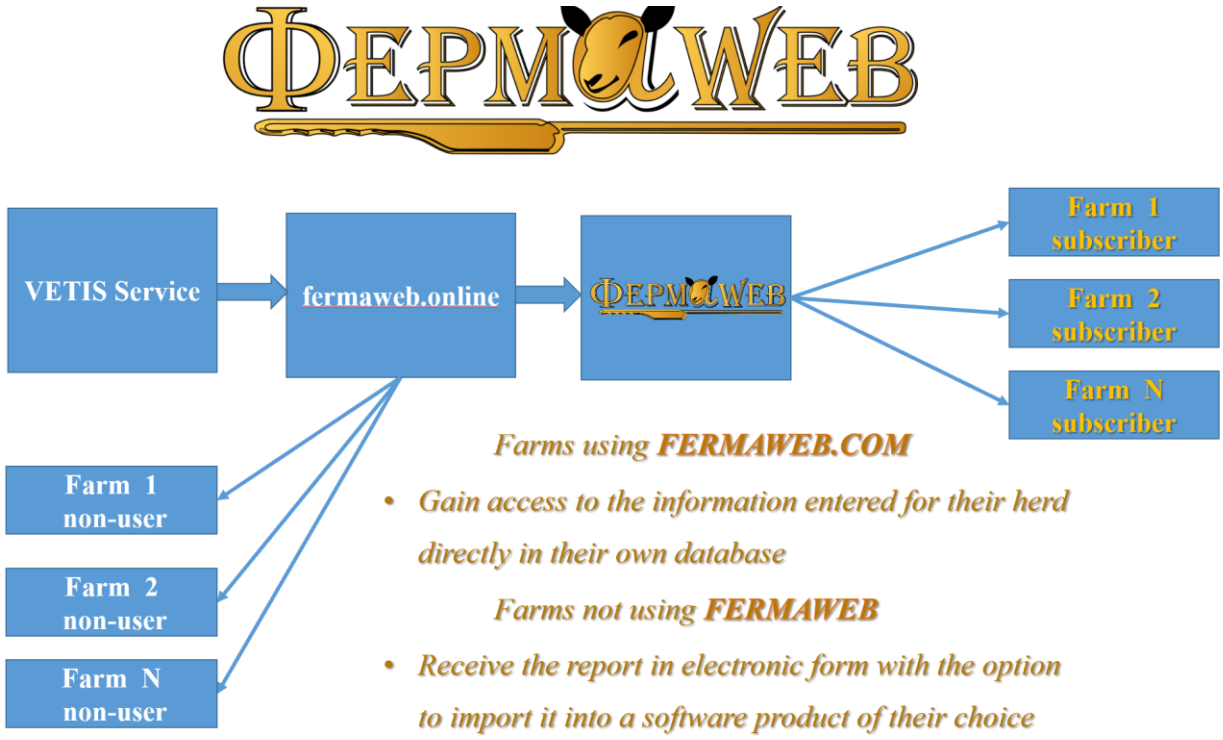

Figure 3.2 – Possible interaction of the farm management systems with the BFSA VetIs in the direction of receiving and synchronizing data with internal records
(*source: FermaWEB – herd management system*)

Risks of non-compliance and double standards.

The study shows that the lack of digital connectivity between real farm activity and accountability to control authorities leads to serious risks in epidemic situations. The proposed solutions within FermaWeb, including an electronic diary, prescription and slaughter register, are among the essential contributions to improving the traceability and safety of the food chain.

Point 5 of Chapter Three discusses ***Sustainable Models for Smart and Efficient Livestock Farming***, with 5 specific farms examined in paragraph 1. The results of the analysis have been tested and evaluated for compliance with the research thesis and the formulated hypotheses.

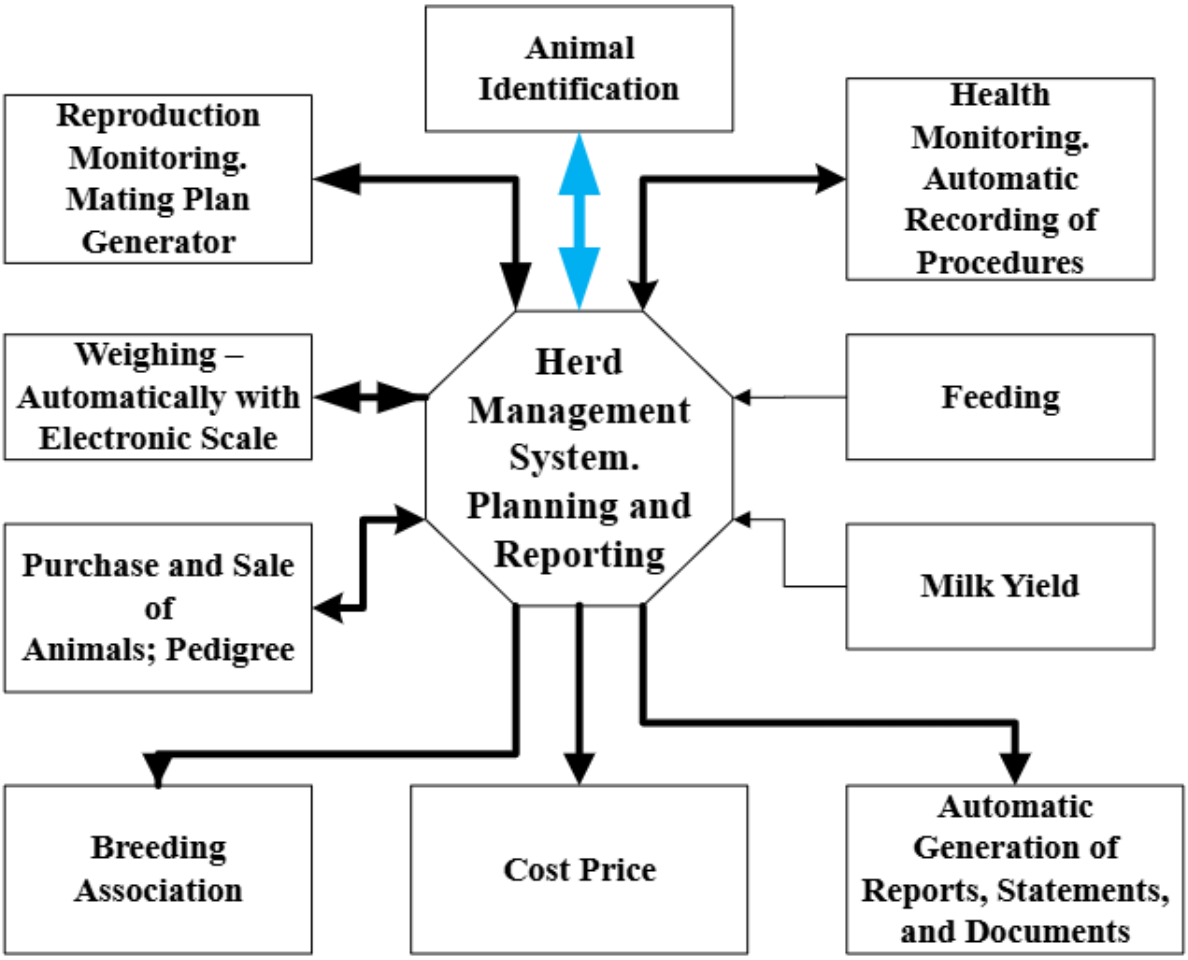

Figure 3.3 – Digitization of processes in a livestock farm 1

(*Source: Author's image*)

Paragraph 2, point 5 of Chapter Three discusses ***Good Practices and Innovative Projects for Digitalization in Livestock Breeding Worldwide.***

Leading European and international initiatives such as SmartCow, 4D4F, SmartAgriHubs, IoF2020, TE-Food, DeepMilk and the national program "Antibiotic-free sheep breeding" are analysed. The projects were evaluated on the implemented technologies, data management models and their applicability in the context of digital transformation. Based on a comparative analysis, the main challenges are outlined, such as high investment costs, lack of qualified personnel, incompatibility between systems, the need for ethical standards and a change in organizational culture.

Point 6 of Chapter Three discusses ***the Perspectives and Guidelines for the Development of Digitalization and Digitalization of Livestock Breeding in Bulgaria.***

Specific guidelines for the development of digitalization in animal husbandry have been analysed and formulated, tailored to the specifics of the sector, the needs of farmers and good European practices. **Raising awareness and digital culture** among livestock breeders through trainings, demonstrations and practical seminars, including the use of the developed system *FarmWEB* as a learning platform.

- **Connecting with scientific achievements and innovation**, through targeted funding and support for the implementation of technologies, including AI-based selection solutions.
- **Improving access to digital technologies** through investments in infrastructure, internet connectivity, hardware and software, as well as through incentives such as subsidies, loans and advice.
- **Development of educational programs and qualifications** aimed at acquiring practical skills for working with digital systems.

- **Creating standards and protocols for compatibility and security** to ensure effective integration between different systems and data protection.
- **Fostering cooperation between actors in the value chain**, by building networks, clusters and platforms for sharing data and resources.
- **Supporting innovation and competitiveness** through the use of national and European research and development programmes

At the end of Chapter 3, the following conclusions are formulated

1. **Digitalization in animal husbandry is fragmented** – over 70% of farms implement individual solutions without integration and without sufficient training.
2. **Animal identification is a key process** – without it, there is no effective breeding and management of the herd. The actual use of electronic identification is limited.
3. **Integration between processes is critical** – the lack of connectivity leads to losses and organizational problems, especially in processing and realization of production.
4. **Main challenges** – lack of qualified personnel, high investment costs, complexity of technologies, lack of strategy.
5. **Artificial intelligence has significant potential** – in managing reproduction, it leads to economic benefits and increased productivity.
6. **State platforms (VetIs) are poorly integrated** – an API for data automation and synchronization is needed.
7. **Sustainable models and good practices** – international projects show that digitalization is possible, but requires standards, compatibility and a change in organizational culture.
8. **Prospects for Bulgaria** – training, access to technology, funding, standards and cooperation between the participants in the chain are needed.

CONCLUSION:

As a result of the study of the dissertation on the topic "Digitalization of animal husbandry – problems and opportunities" and the in-depth analysis carried out in the context of the dynamics of the business environment and the development of innovative technologies, the following conclusions can be distinguished:

1. The current level of digitalization of livestock breeding in Bulgaria is relatively low, compared to the opportunities that exist on a European and global scale.

2. The animal identification system, which is the basis of all processes in farm management, is reduced to "inventory". to meet the needs of state control.

3. Innovative farms that use technological solutions to optimize their business rely on European and national support. The use of the methodology of the company's preliminary research and the creation of a specific plan for consistent implementation and evaluation of the effect of the innovation is a necessary opportunity.

4. There is a need for specific solutions for communication with the state administration and improvement of control systems based on integration with external systems. This would ease the administrative burden on the farm business.

5. Supporting innovation processes and deepening the connection with science will increase the competitiveness of animal husbandry.

6. Companies that cover and digitize all business processes "from the field to the fork" have more opportunities.

The analysis of the data used in the dissertation and the personal justifications and contributions of the author fully support the thesis set out in the introductory part, through the verification of the relevant hypotheses, namely:

Hypothesis A – The digitalization of a livestock farm depends on its size, the type of animals that are kept, their breed and direction, and the technology by which they are raised.

Hypothesis B: The digitalization strategy in each individual farm should be carefully selected depending on the form of management and the views and qualifications of the owners and management staff.

Hypothesis C – Software solutions for control and management of the livestock business by the state are of key importance to the speed and direction of business digitalization.

Hypothesis D: The livestock business support system creates prerequisites for serious discrepancies and incorrect practices due to the lack of a sufficient level of digitalization on the farm.

Hypothesis D – tracking the process "from field to fork" and the quality of production is achievable with the digitalization of all processes along the chain.

The study confirms that properly selected and integrated digital technologies in animal husbandry lead to an increase in the quality and profitability of production, with minimal impact on the environment. Based on the analysis of specific farms and innovative solutions, hypotheses related to the influence of the size and type of the farm, the management model, the role of state systems, the effect of subsidies and the need for digitalization along the entire production chain "from field to fork" have been validated. The theoretical model of the "Ideal Farm" was created.

Reference scientific contributions to the dissertation

The following research contributions are presented in the dissertation:

1. A theoretical model has been developed for optimizing production costs in meat production through the integration of PLF, IoT, and AI, linked to traceability and quality assessment—a model oriented toward the concept of an "Ideal Farm."
2. A systematization of digital technologies has been carried out in three areas (identification, traceability, automation), including a managerial classification of identification methods.
3. A typology of livestock farms and a methodology for assessing the impact of digital solutions (on a scale of 1–10) have been established, supporting the selection of investment priorities. The phenomenon of "virtual sheep" has been analyzed, and an evaluation of potential losses resulting from its existence has been performed.
4. A prototype of a reproduction management system (mating plan) has been created, using artificial intelligence to prevent inbreeding and optimize inseminations. Data and partnerships for its training and validation are described.
5. A process-chain framework for traceability has been developed, integrating EID, GS1, and blockchain for quality management and customer trust.
6. Empirical contribution: Extensive field coverage (100+ farms in Bulgaria and reference visits in 4 countries), providing validated practical guidelines for implementation.

LIST of the publications of a PhD student

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PhD Degree No: d010422269

PhD program: "Economics and Management (Agrarian Economics)"

Dissertation on the topic: "DIGITAL TRANSFORMATION OF ANIMAL HUSBANDRY – PROBLEMS AND OPPORTUNITIES"

1. **Report** "Innovations in Livestock Breeding - Contribution to the Green Economy"; Proceedings of the conference "Circular Economy in the Context of Industry 4.0 – Society 5.0" relation, 21-22.10.22, Svishtov; author: Petar Chernaev
2. **Article** "The Social Effect on Rural Development in Digitalization and Automation of Livestock Breeding";
   Proceedings of the Round Table on "Theory and Practice for Sustainable Management and Development of Rural Territories in Bulgaria" – 31.05.2024;
   author: Petar Chernaev
3. **Article** "Digital transformation of the livestock business: challenges and opportunities";
   Annual Almanac "Research of PhD Students", Book 19 – 2023;
   author: Petar Chernaev
4. **Discourse** DIGITAL SOLUTIONS FOR THE ADMINISTRATION OF LAND MANAGEMENT PROCESSES IN THE REPUBLIC OF BULGARIA;
   Collection of reports: „INNOVATIVE DEVELOPMENT OF AGRICULTURAL BUSINESS AND RURAL AREAS “, IDARA, 28-29 IX 2023 г., Sofia ;
   authors NIKOLOVA, MARINA, CHERNAEVA, PENKA, CHERNAEV, PETAR
5. **Article** „INNOVATIONS IN BEEF BREEDING - OPPORTUNITIES AND PROBLEMS“; author: CHERNAEV, PETAR
   SHS Web of Conferences 176, 03006 (2023);
   DOI: https://doi.org/10.1051/shsconf/202317603006;

DECLARATION OF ORIGINALITY AND AUTHENTICITY

by Eng. Petar Angelov Chernaev

In connection with the procedure for acquiring the educational and scientific degree of "Doctor" in the doctoral program "Economics and Management (Agrarian Economics)", I declare that:

1. The results and contributions in the dissertation on the topic: "**Digital transformation of animal husbandry – problems and opportunities**" are original and are not borrowed from research and publications in which the author has no participation.
2. The information presented by the author in the form of copies of documents and publications, personally compiled references, etc. corresponds to objective truth.
3. The results that have been obtained, described and/or published by other authors are duly and thoroughly cited in the bibliography.

Svishtov Doctoral student: .....

/Petar Chernaev/