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AI-Welfare: An intelligent system for assessing sheep welfare under climate challenges

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ABSTRACT

The article presents the AI-Welfare concept as an intelligent analytical system for the comprehensive assessment of sheep welfare, designed to integrate different groups of indicators and provide an overall characterization of the animal's condition. The proposed approach is based on the combination of physiological, physical, behavioural, clinical and environmental indicators, enabling welfare to be considered as a dynamic and multifaceted state rather than as a set of individual parameters. Particular attention is given to the need to simultaneously consider the functional condition of the animal, its behavioural activity, housing conditions and potential risk factors. The main groups of indicators suitable for the comprehensive assessment of sheep welfare are identified, and the feasibility of integrating them into a unified analytical system is substantiated. Physiological indicators include heart rate, respiratory rate and body temperature; physical indicators include body condition and other characteristics of physical status; behavioural indicators include locomotor activity, resting, feeding and social behaviour; while clinical indicators encompass signs of disease, injury, discomfort and stress. The findings confirm the feasibility of simultaneously using several complementary indicators, since an individual parameter does not always adequately reflect the overall welfare status of an animal. Comprehensive assessment makes it possible to consider the relationships between physiological responses, physical condition, behaviour and environmental conditions. The developed AI-Welfare model provides for a sequential process of sensor-based data acquisition, collection of primary signals, data cleaning and synchronization, data transmission and integration with the results of professional assessment. The subsequent stage involves AI-based analysis aimed at identifying patterns, changes in indicator dynamics, deviations from individual or group profiles, and potential welfare risks. Its practical significance lies in the possibility of integrating data from different sources into a unified monitoring system that can be used to improve the objectivity of welfare assessment, enhance flock management, and support the principles of One Welfare and contemporary approaches to responsible livestock management.

Keywords: Sheep; welfare; AI-Welfare; artificial intelligence; physiological indicators; behaviour; clinical indicators; sensor-based monitoring; environmental factors; integrated profile; comprehensive assessment; One Welfare

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Relevance. Modern livestock production is moving from assessing productivity as the primary criterion of efficiency towards comprehensive management of animal health, welfare, resilience, and adaptive capacity. Animal welfare is currently regarded as a multidimensional biological state shaped by nutrition, the physical environment, health status, behavioural interactions, and the animal's psychological and emotional state [1], [2].

This approach fundamentally changes the assessment methodology: it is not sufficient to establish only the presence or absence of disease or compliance of housing conditions with regulatory requirements; it is also necessary to determine how the animal actually responds to environmental conditions and the management system.

For sheep, this issue is particularly important due to the complexity of simultaneously monitoring physiological status, behaviour, nutrition, locomotor activity, social interactions, and productivity. A systematic analysis by Llonch et al. [3] identified a substantial number of potential animal-based indicators for assessing sheep welfare, while emphasizing the need to evaluate their validity and practical applicability. Zufferey et al. [4] also highlight the importance of indicators such as body condition, lameness, health status, and behavioural characteristics for the comprehensive assessment of sheep welfare. Therefore, a modern monitoring system should not rely on a single indicator but rather on the integration of a set of interrelated animal-based indicators.

Traditional welfare assessment methods generally involve periodic clinical examinations, visual assessment of behaviour, determination of body condition and physiological parameters, and analysis of productivity. Although this approach remains essential, it has certain limitations: it is labour-intensive, depends on the operator's level of expertise, primarily characterizes the animal's condition at a specific point in time, and does not always allow early, subclinical, or gradual changes in welfare to be detected in a timely manner.

It is at this stage that the scientific rationale for applying Precision Livestock Farming (PLF) technologies emerges. Berckmans [5] describes PLF as an approach to continuous, automated animal monitoring based on sensor technologies and data analysis. Schillings et al. [6] emphasize that PLF technologies can enhance welfare monitoring by enabling the continuous acquisition of information on animal behaviour, physiology, and housing conditions.

For small ruminants, this area is of particular importance. The review by Morgan-Davies et al. [7] demonstrates the considerable potential of precision livestock farming technologies for sheep welfare management, including the use of automated monitoring of behaviour, activity, health, and environmental conditions. The authors also highlight the potential for moving beyond simple data collection towards risk management and early-warning systems.

At the same time, the accumulation of large amounts of data does not, in itself, ensure more effective welfare monitoring. Modern digital systems can simultaneously record video, locomotor activity, feed and water intake, environmental temperature and humidity, physiological parameters, and productivity. However, this creates a fundamentally new scientific challenge: how to transform heterogeneous, multidimensional, and dynamic data into an integrated, biologically interpretable assessment of the animal's welfare status.

Artificial intelligence and machine learning represent promising tools for addressing this challenge. Researchers [8], [9] demonstrate that digitalization and AI open up new opportunities for monitoring behaviour, health, productivity, and management in sheep farming. Individual studies have also demonstrated the potential of machine-learning algorithms for the automated recognition of behavioural patterns and deviations in sheep welfare status. However, the technological capability to automatically record a particular indicator does not necessarily mean that a system is capable of comprehensively assessing animal welfare.

This defines the key scientific problem. At present, numerous individual methods for assessing sheep welfare, sensor technologies, computer vision systems, and machine-learning algorithms are available. However, an integrated approach in which behavioural, physiological, productive, and environmental indicators are combined into a unified welfare assessment system, with risk-level determination and early-warning capability, remains insufficiently developed.

In this context, the AI-Welfare concept is considered not merely as an automation of animal observation, but as a new organizational and analytical model that combines four interrelated levels: **monitoring → data integration → intelligent analysis → welfare assessment and early warning.**

A fundamental feature of this approach is the transition from recording individual deviations to identifying complex patterns that may indicate deterioration in animal welfare. For example, a simultaneous decrease in activity, changes in respiratory rate, an increase in body temperature, alterations in feed intake, and unfavourable temperature and humidity conditions may have

substantially greater diagnostic value when considered collectively than when each indicator is assessed separately.

Importantly, AI-Welfare should be based not only on the technical accuracy of algorithms but also on the biological validity of the indicators and their relationship to the actual assessment of animal welfare. Therefore, a model in which automated monitoring results are complemented by expert and clinical assessment is particularly promising. Such an approach makes it possible to calibrate algorithms and reduce the risk of misinterpreting digital signals.

Thus, the relevance of developing AI-Welfare is determined by the need to create a new generation of sheep welfare monitoring systems that are continuous, multiparametric, objective, adaptive, and focused not only on detecting problems but also on their early identification. This approach is consistent with the modern One Welfare concept and the development of Precision Livestock Farming (PLF), providing a scientific basis for a transition from reactive management to proactive management of animal welfare.

The scientific novelty of the AI-Welfare concept lies in combining animal-based indicators, physiological parameters, behavioural characteristics, and microclimatic parameters within a unified analytical framework, enabling the generation of an integrated welfare index, assessment of risk levels, and early warning of potential deterioration in animal welfare.

Aim and Objectives of the Study. The aim of the study is to develop and substantiate the conceptual framework of the AI-Welfare intelligent system for the comprehensive assessment of sheep welfare through the integration of behavioural, physiological, morphological, productive, and environmental indicators, and to determine its potential for the early detection of welfare risks under changing housing conditions.

Materials and Methods. The methodological framework of the study was based on the principles of modern welfare science, animal-based assessment, and Precision Livestock Farming (PLF), with the use of artificial intelligence approaches for the integration and interpretation of heterogeneous data. The methodological approach combined the principles of animal welfare assessment based on indicators directly related to the animal's condition, the concept of Precision Livestock Farming, and the capabilities of intelligent analysis of multiparametric data.

The selection of welfare indicators was based on contemporary scientific concepts, including the Five Domains Model [10], methodological recommendations of the Farm Animal Welfare Council (FAWC), EFSA recommendations (2012), and the European Union regulatory framework (Directive 98/58/EC; Council Directive 2008/119/EC), as well as the national requirements for farm animals in Ukraine. This methodological framework ensured the objectivity, scientific validity, practicality, and comprehensiveness of the assessment. The scientifically substantiated approach involved combining animal-based indicators (physiological status, behaviour, and health) with resource- and environment-based indicators (housing conditions, microclimate, bedding quality, and access to feed and water).

The study object comprised sheep subjected to a comprehensive assessment of their physiological, morphological, behavioural, and productive status, with simultaneous consideration of the environmental conditions in which they were housed. The information base was formed using the results of the examination of 137 animals. The assessment included indicators characterizing different aspects of animal welfare: body condition score (BCS), heart rate, respiratory rate, body temperature, locomotor activity, behaviour, feed and water intake, social interactions, productive performance, and overall clinical condition.

This methodological approach made it possible to move beyond the assessment of individual indicators towards the development of an integrated animal welfare profile, providing a basis for the subsequent application of AI-based analysis to identify patterns, deviations, and potential welfare risks.

Based on the developed scheme for assessing sheep welfare, a sheep welfare assessment protocol was developed. The protocol was structured according to a comprehensive approach to assessing the physiological, behavioural, and productive status of animals, as well as their housing

conditions. The assessment system included indicators characterizing physiological status, behaviour and activity, physical condition and body condition, health status, productive performance, and environmental parameters.

The developed protocol was used as a basis for the subsequent integration of instrumental monitoring data and AI-based analysis in the formation of individual and group sheep welfare profiles.

To facilitate the operational collection of information on the functional status of sheep, Serhii Borysovykh Kondratiev, Associate Professor at the Department of Information Systems of Odesa Polytechnic National University, developed a multiparametric animal status sensor, which serves as a primary information element of the AI-Welfare system. The sensor is designed for continuous or periodic recording of physiological and behavioural parameters, followed by transmission of the acquired data to a system for data storage, synchronization, integration, and intelligent analysis (Table 1).

Table 1. Information Parameters Recorded by the Sensor

Block	Indicator	Information value
Physiological status	Heart rate	Characterizes cardiovascular response and functional state of the animal
Physiological	Respiratory rate	Assessment of the physiological response
Physiological	Body temperature	Characterization of the thermoregulatory status
Behavioural	Locomotor activity	Activity-rest ratio
Behavioural	Duration of activity/rest	Formation of the behavioural profile
Information	Data transmission	Real-time delivery of information to the system
Analytical	Integration of indicators	Formation of a comprehensive assessment of the animal's welfare status

Source: compiled by the authors

Statistical processing of the obtained data included determination of the arithmetic mean (M), standard error of the mean (m), minimum and maximum values, as well as assessment of the nature of relationships between individual indicators. To assess the agreement between the AI-Welfare results and expert assessment, correlation and comparative analyses were planned.

The overall methodological concept of the study was based on a transition from the traditional assessment of individual indicators to multiparametric monitoring and the development of an integrated sheep welfare profile, which constitutes the foundation of the proposed AI-Welfare system.

Results and Discussion. The research was aimed at the development and preliminary validation of a comprehensive sheep welfare assessment system combining direct assessment of the physical and physiological status of animals, behavioural observation, sensor-based recording of indicators, and assessment of environmental conditions. The system was based on a previously developed assessment scheme, which included the selection and systematization of welfare indicators, determination of methods for their recording, and establishment of criteria for interpretation of the obtained results.

Particular attention was paid to the use of an animal status monitoring sensor, which enables objective recording of parameters characterizing the physiological status, locomotor activity, and housing conditions of sheep. The application of a sensor-based approach makes it possible to move from a one-time assessment of an animal's status towards dynamic monitoring, which is important for the timely detection of changes and deviations in behavioural and physiological parameters.

In the developed protocol, data obtained using sensors were not considered in isolation. They were integrated with the results of clinical examination, body condition assessment, behavioural evaluation, health status assessment, and other welfare indicators. This approach enabled the development of a multicomponent welfare assessment system combining direct measurements, behavioural observations, and environmental parameters.

To provide an objective characterization of the physiological status of the sheep, the developed welfare assessment protocol included a set of physiological indicators reflecting the functional state of the animal's organism. These indicators constitute an important component of the comprehensive assessment, as their changes may be associated with physiological load, discomfort, responses to housing conditions, and other factors (Table 2).

Table 2. Physiological Indicators

Indicator	M ± m	Min	Max	Score (1-5)	Comment
Heart rate, beats/min	78.0±0.38	70	88	3.7	Mild stress
Respiratory rate, breaths/min	22.0±0.34	19	26	3.8	Ventilation control
Body temperature, °C	38.5±0.13	37.7	39.2	3.9	Within the normal range, with no signs of fever
Body condition score (BCS), points	4.3±0.06	4.0	4.7	4.3	Well-conditioned
Skin / fleece condition, points	3.0±0.05	2.5	3.5	3.9	Reflects hygiene and fleece condition
Mucous membrane colour, points	4.0±0.04	3.0	5	4.0	Within the normal range; an indicator of health
Mean				3.9	

Source: compiled by the authors

The obtained results indicate the need to consider several physiological indicators simultaneously. In particular, heart rate reflects the functional status of the cardiovascular system, respiratory rate characterizes respiratory function and the animal's response to housing conditions, whereas body temperature reflects the overall physiological status.

The use of sensor-based recording of these indicators over time provides additional value, as it enables assessment not only of an individual measurement but also of the pattern of its change over time.

An important component of the developed protocol was the assessment of the animals' physical condition. Body condition was determined using a scoring scale and used as one of the indicators of physical welfare. The mean body condition score was 4.3±0.06 points. The variability of the indicator was relatively low, ranging from 4.0 to 4.7 points. This result was considered together with physiological and behavioural indicators, since body condition alone does not provide a comprehensive characterization of animal welfare.

A separate area of the study focused on the assessment of sheep behavioural responses. For this purpose, the system included indicators of locomotor activity, resting, changes in body position, and overall activity (Table 3).

Changes in locomotor activity, duration of rest, and body position recorded by the sensor can be used as early behavioural indicators of potential welfare impairment. A decrease in activity or a change in the usual activity-to-rest ratio requires further verification using physiological and clinical indicators, as these changes alone are not specific to any particular welfare impairment.

The temporal integration of behavioural data with environmental parameters is also important. Synchronized analysis of animal activity and microclimatic conditions makes it possible to determine whether behavioural changes are associated with housing conditions. At the same time, comparison of sensor-derived data with body temperature, heart rate, respiratory rate, and body condition assessment increases the reliability of the comprehensive interpretation of the animals' status.

Table 3. Behavioural Indicators of Sensor-Based Monitoring

Indicator	M ± m	Min	Max	Score (1-5)	Comment
Activity	3.6±0.07	3	5	3.7	Moderate / Stress and disease control
Rest / Sleeping status	3.8±0.06	3	5	4	Adequate / Ensure comfortable resting areas
Social behaviour	3.9±0.06	3	5	4	Stable
Feeding behaviour	4.1±0.05	3	5	4	Active
Body cleanliness / hygiene	3.8±0.06	2	5	4	Reflects grooming and bedding condition
Aggression	2.8±0.05	2	4	3	Occasional
Use of pasture / available space	4.0±0.07	2	5	4	Control of uniform grazing and access to space
Detection of fear / anxiety	3.5±0.07	2	5	4	Requires monitoring of stress factors
Interaction with humans	3.7±0.06	2	5	4	Positive response to care and human contact
Use of equipment / structures	3.8±0.06	2	5	4	Ensures activity and safety
Mean				3.7	

Source: compiled by the authors

Thus, behavioural sensor monitoring should be considered a component of a multilevel welfare assessment system, rather than an independent diagnostic criterion. Its integration with physiological, physical, clinical, and environmental indicators provides an information basis for developing an individual welfare profile and for subsequent application of AI-based analysis to automatically detect atypical behavioural patterns.

Environmental parameters were also considered in the welfare assessment system. Sensor-based monitoring of temperature and relative humidity makes it possible to characterize the conditions in which the animals are kept and to relate these conditions to their physiological and behavioural responses.

The main environmental parameters subject to recording and subsequent interpretation within the sheep welfare assessment system are presented in Table 4.

The analysis of environmental parameters indicates that microclimatic conditions are an important external component influencing sheep welfare. At the same time, when assessing the effects of the environment, not only the absolute value of an individual parameter but also its dynamics and the duration of exposure of animals to specific microclimatic conditions are of fundamental importance. Therefore, continuous or periodic recording of temperature and humidity makes it possible to identify periods of increased environmental load that may remain undetected by a single measurement.

As a result of the research, the concept and model of AI-Welfare – an intelligent system for the comprehensive assessment of sheep welfare – were developed. The system is based on the integration of physiological, physical, behavioural, clinical, and environmental indicators within a unified analytical framework. Conceptually, AI-Welfare considers animal welfare as a dynamic and multidimensional state formed through the interaction of the functional status of the organism, behaviour, health, and environmental conditions. Accordingly, the assessment is not limited to recording individual indicators but involves their comprehensive comparison, analysis of interrelationships, and evaluation of changes over time.

Table 4. Environmental Indicators

Indicator	M ± m	Min	Max	Score (1-5)	Comment
Air temperature, °C	18.0±0.30	15	22	3.9	Microclimate control
Humidity, %	60.0±0.40	55	65	3.8	Humidity control
Cleanliness of the housing area	4.0±0.07	3	5	4	Regular cleaning
Bedding quality	4.0±0.07	2	5	4	Comfortable for resting
Lighting	4.0±0.06	3	5	4	Appropriate for the physiological rhythm
Ventilation	4.0±0.07	3	5	4	Ensures fresh air and reduces stress
Access to feed	4.2±0.06	3	5	4	Control of feed availability and equitable access
Access to water	4.1±0.06	3	5	4	Access ensured
Housing facilities / protection from weather conditions	4.2 ± 0.4	2	5	4	Enhances comfort and safety
Condition of feeders and waterers	4.0 ± 0.5	2	5	4	Feeders and waterers are sufficient in number and easily accessible to sheep
Air quality (dust, odours)	3.8 ± 0.6	2	5	4	Air quality is satisfactory. Minimal discomfort
Available space per animal	4.1±0.35	2,5	5	4	Sufficient space for movement and social behaviour
Noise / stress from external factors	3.7±0.5	2	5	4	Moderate noise level. Minimal stress
Access to shade and sun protection	4.3±0.4	2	5	4	The flock has sufficient access
Mean				3.9	

Source: compiled by the authors

The developed AI-Welfare model provides for the sequential processing of information from the animal and its environment through sensor-based recording and professional clinical observation, followed by data cleaning, synchronization, standardization, and integration of heterogeneous data. The central analytical component of the model is artificial intelligence, which enables multiparametric analysis of the collected information, assessment of its temporal dynamics, recognition of typical and atypical patterns, detection of deviations from individual or group profiles, and identification of potential welfare risks. Of particular importance is the synchronization of data on the physiological and behavioural status of sheep with environmental parameters, which makes it possible to identify relationships between changes in microclimatic conditions and the animals' physiological responses.

The conceptual foundation of AI-Welfare is the transition from the static assessment of individual indicators to an integrated dynamic welfare profile of the animal. This approach makes it possible to consider welfare not as a one-time measurement outcome, but as a process requiring continuous monitoring and timely interpretation of changes.

Thus, AI-Welfare represents not merely an automated data-collection system, but a new intelligent and analytical concept for sheep welfare assessment, in which sensor technologies provide objective data acquisition, while artificial intelligence transforms heterogeneous data into a structured assessment of the animal's status and information to support management decisions. The practical value of the model lies in its ability to facilitate the timely detection of undesirable changes, determine the need for additional clinical examination, support adjustments to housing conditions, and enable subsequent evaluation of the effectiveness of the measures taken.

Importantly, AI complements professional expert assessment, combining objective monitoring data with expert interpretation.

Thus, the AI-Welfare concept establishes a closed intelligent cycle: “recording → integration → AI analysis → assessment → welfare profile → decision support → response → repeated monitoring,” providing a basis for the transition from traditional control of individual indicators to comprehensive, dynamic, and proactive management of sheep welfare.

The primary objective of the next stage is to develop a comprehensive conceptual model that integrates monitoring of the animal’s status and environmental parameters, comprehensive assessment of physiological, physical, behavioural, and clinical indicators, AI-based analysis of their interrelationships and dynamics, and the development of an integrated welfare profile. Its subsequent experimental testing and validation will provide a basis for developing an adaptive model for sheep welfare management, focused on the early detection of risks, maintenance of a stable animal status, and timely adjustment of housing conditions.

Conclusions. Based on the comprehensive assessment, the physiological indicators of sheep welfare corresponded to a stable functional status: heart rate, respiratory rate, and body temperature remained within acceptable physiological ranges. The physical condition of the animals was characterized by adequate body condition, indicating a satisfactory somatic status and the absence of a pronounced deficit in the body’s physical reserves.

The behavioural component of welfare was characterized by the preservation of basic activity and resting patterns. The use of sensor-based recording made it possible to assess not only the level of activity but also its dynamics and potential deviations from the individual animal profile.

Environmental parameters were incorporated into the integrated assessment as external welfare factors, enabling changes in microclimatic conditions to be considered in relation to the physiological and behavioural responses of sheep.

Based on the obtained results, the AI-Welfare concept and model were developed, integrating physiological, physical, behavioural, clinical, and environmental indicators into a unified system. AI-based analysis is used to assess their interrelationships, temporal dynamics, and potential deviations.

Further research will focus on the accumulation of dynamic data, development of individual welfare profiles, and validation of the AI-Welfare model for the early detection of changes in sheep welfare under different levels of environmental and climatic load.

Conflict of Interest: The authors declare that they have no conflicts of interest, including financial, personal, authorship-related, or any other interests that could have influenced the research or the results reported in this article

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Data Availability: The data were collected through the public API of the GitHub platform. The list of assistant accounts with classification rules, aggregated repository- and year-level participation tables, comparison results (Tables 5–7), and figure-generation scripts are available from the authors upon reasonable request. The complete dataset is being prepared for public release with a persistent identifier, as indicated in [14]

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AI-Welfare: інтелектуальна система оцінювання благополуччя овець в умовах кліматичних викликів

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АНОТАЦІЯ

У статті представлено концепцію AI-Welfare як інтелектуально-аналітичної системи комплексного оцінювання благополуччя овець, орієнтованої на інтеграцію різних груп індикаторів та формування цілісної характеристики стану

тварини. Запропонований підхід ґрунтується на поєднанні фізіологічних, фізичних, поведінкових, клінічних і середовищних показників, що дає змогу розглядати благополуччя як динамічний комплексний стан, а не як сукупність окремих параметрів. Особливу увагу приділено необхідності одночасного врахування функціонального стану тварини, її поведінкової активності, умов утримання та потенційних факторів ризику. Визначено основні групи індикаторів, доцільні для комплексного оцінювання благополуччя овець, та обґрунтовано можливість їх інтеграції в єдину аналітичну систему. До фізіологічних індикаторів віднесено частоту серцевих скорочень, частоту дихальних рухів і температуру тіла; до фізичних – показники вгодованості та інші характеристики фізичного стану; до поведінкових – рухову активність, відпочинок, кормову та соціальну поведінку; до клінічних – ознаки захворювань, травм, дискомфорту та стресового стану. Отримані результати підтверджують доцільність одночасного використання кількох взаємодоповнювальних індикаторів, оскільки окремий показник не завжди відображає загальний стан благополуччя тварини. Комплексне оцінювання дає змогу враховувати взаємозв'язок між фізіологічними реакціями, фізичним станом, поведінкою та умовами середовища. Розроблена модель AI-Welfare передбачає послідовний процес сенсорної реєстрації інформації, отримання первинних сигналів, їх очищення та синхронізації, передавання й інтеграції даних із результатами професійного оцінювання. Наступним етапом є AI-аналіз, спрямований на виявлення закономірностей, змін у динаміці показників, відхиленні від індивідуального або групового профілю та потенційних ризиків для благополуччя. Її практичне значення полягає у можливості об'єднання даних від різних джерел у єдину систему моніторингу, що може бути використана для підвищення об'єктивності оцінювання благополуччя, удосконалення управління стадом і підтримки принципів One Welfare та сучасних підходів до відповідального утримання сільськогосподарських тварин.

Ключові слова: вівці; благополуччя; AI-Welfare; штучний інтелект; фізіологічні індикатори; поведінка; клінічні індикатори; сенсорний моніторинг; середовищні фактори; інтегрований профіль; комплексне оцінювання; One Welfare

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