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A concept for application of integrated digital technologies to enhance future smart agricultural systems

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ABSTRACT

Future agricultural systems should increase productivity and sustainability of food production and supply. For this, integrated and efficient capture, management, sharing, and use of agricultural and environmental data from multiple sources is essential. However, there are challenges to understand and efficiently use different types of agricultural and environmental data from multiple sources, which differ in format and time interval. In this regard, the role of emerging technologies is considered to be significant for integrated data gathering, analyses and efficient use. In this study, a concept was developed to facilitate the full integration of digital technologies to enhance future smart and sustainable agricultural systems. The concept has been developed based on the results of a literature review and diverse experiences and expertise which enabled the identification of stat-of-the-art smart technologies, challenges and knowledge gaps. The features of the proposed solution include: data collection methodologies using smart digital tools; platforms for data handling and sharing; application of Artificial Intelligent for data integration and analysis; edge and cloud computing; application of Blockchain, decision support system; and a governance and data security system. The study identified the potential positive implications i.e. the implementation of the concept could increase data value, farm productivity, effectiveness in monitoring of farm operations and decision making, and provide innovative farm business models. The concept could contribute to an overall increase in the competitiveness, sustainability, and resilience of the agricultural sector as well as digital transformation in agriculture and rural areas. This study also provided future research direction in relation to the proposed concept. The results will benefit researchers, practitioners, developers of smart tools, and policy makers supporting the transition to smarter and more sustainable agriculture systems.

1. Introduction

Agricultural business sectors want to increase their productivity to meet the needs of a growing human population and tackle existing challenges such as climate change, food scarcity, energy, labour and environmental issues including water quality, biodiversity and soil health [1,2]. At the same time, digital transformation is seen to deliver beneficial opportunities for the agricultural sector [3,4]. For instance, digitalization explicitly underpins all objectives under the new Common Agricultural Policy (CAP: 2023-27) which will be supported by the development of a European data space for agriculture [5].

Agriculture has delivered innovations for centuries. The development and adoption of sensors has allowed precision farming to collect unprecedented resolution of spatiotemporal information about the

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agricultural system [6]. Using additional smart technologies along with effective use of data can increase production efficiency [7] and in this context, digital technologies such as cloud and edge computing, Blockchain (BC), Artificial Intelligence (AI), big data and Internet of Things (IoT) are growing in public use [8]. These technologies along with remote sensing and Information and Communication Technology (ICT) could support farmers through increased performance and efficiency of farming systems, with utilization of the most effective farm management strategies. The technologies convert complex data into actionable knowledge and support integrated, real time decision-making approaches [9,10]. This potential to analyse and understand farm data through digitalization scenarios may help to develop more profitable, productive, and sustainable farming strategies in agriculture.

Digital technologies in smart farming, based on application of big data analysis, IoT, AI, remote sensing, robotic and smart sensors can help to use real time information accurately and improve yield as well as productivity [11,12]. In this context, data driven approaches using large quantities of sensor-based generated data (big data) can be used to develop early warning, farm management and decision-making systems for improved soil characteristics, water use efficiency, yields, and health assessments of crop, animal and horticultural products. In digital farming, big data is changing the traditional approaches and along with machine learning techniques can provide high performance information to unravel, quantify and understand data intensive processes in farm operations [13]. It can also benefit the financial management and development of smart agriculture systems [14] of the future.

The data generated and used in digital farming is wide ranging. It can be categorized as climate, soil and water, crop and animal, bio security, genomic, farm management and remote sensing data sets [15,16] which are obtained from various sources such as on farm sensors, wearable sensors, drone and multi-platform remote sensing, weather stations, farm machinery and robots. By using digitalization approaches for instance, characterization of soils has moved from coarse categorizations to detailed lateral, vertical, and temporal levels as well as information of individual soil properties and components such as texture, structure, pH, macro and micro nutrients, water content, organic matter content and carbon bixation etc. [17]. Digital farming solutions such as app and web-based software coupled with machine learning techniques are now able to improve, for example, sustainable precision irrigation [18]. If improvements are made to reduce the existing challenges, machine learning has a promising potential to cope with agricultural big data [9,19]. The IoT and digitalization approaches have been used to improve crop productivity and reduce grain losses. Smart digital technologies based on mobile apps are now able to provide prediction models for yield, productivity and health of a crop using historical data sets and weather forecasts and can link to the latest government support and compliance schemes related to farmers and farming [20]. Information from soil, weather, irrigation, plant growth and health status, use of fertilizer and herbicides can now be fused to provide crop management strategies to farmers using smart digital technologies and advanced data analytics techniques. Combining smart digital tools with farm machinery and autonomous machines will help farmers to improve precision and increase technical efficiency and their knowledge for better overall farm management [21,22]. In precision livestock farming, digitalization can also support farmers to predict disease, mitigation pandemic crises, analyse livestock welfare and provide information about individual and group animal behaviour, change in housing conditions, impact of climate change on animals, etc. [23].

Currently digital farm equipment such as yield prediction tools and informed decision making tools [24] or wearable virtual fencing devices [25] are available for use in precision agriculture. However, there is often poor understanding and utilization of the data. The need to learn new technological skills and data interpretation is an additional barrier for farmers who need a trusted, simple, single point of access to relevant, concise and reliable information that can assist with farm management and improve sustainability [26]. Multiple data sources (including multi-sensor data, meteorological and Earth Observation data, map services and historical data sets) differ in format and time interval and require integration. Therefore, there is a need to develop a concept that enables addressing the multiple challenges of combining and using divergent data sources, including large national and farm-based sensor data sets. This requires: understanding the current data sets, data sources, and analysis methods and development of new techniques; structures for management of the data and its governance; and use of appropriate data technologies to add value. Ultimately this will demonstrate the utility and value of upscaled data for more economically resilient and environmentally sustainable farm management.

The overall objective of the paper is to perform a comprehensive literature review of the state of the art for the adoption of smart farming through the use of integrated digital data and sensor-based systems, and to present a data fusion concept for an integrated smart farming system, where information from different sources including ground based and earth observation is integrated to enable the efficient and sustainable use of resources. This could also lead to increased environmental and economic performance, thus contributing to an overall increase in the sustainability and resilience of the agricultural sector. The proposed concept is to:

- integrate real time data and strengthen the capacity for monitoring of production and agri-environmental conditions;
- integrate and manage data from multiple sources from ground, proximal and remote sensing
- develop integrated data platform that can bring crop, pasture, tree, animal and environmental (air, soil, water) data together into a single point access hub;
- use AI effectively in smart farming to analyse and classify data, find patterns which can predict phenomena and enable the development of smart farming digital solutions; and
- develop a decision support systems (DSS) that utilises multiple data sources and mobile sensor integrated platforms with the potential to be robust and reliable under a wide range of possible farming scenarios.

2. Methodology

This paper was based on a literature review and concept development approach. For the literature review, search strings were determined and databases were identified for retrieving relevant peer-reviewed papers. The main databases include Scopus; Web of Science, and Google Scholar. Considering different aspects of smart agriculture, five search strings were determined and Table 1 presents the search

Table 1
Literature search strings used for different focus area.

No.	Focus area	Description of search string	Search results from Scopus
Search string #1	Digital sensors and technologies	Agriculture AND (smart Digital sensors OR Digital Technologies)	600
Search string #2	Application of AI in data analysis and integration	Agriculture AND (smart Digital sensors OR Technologies) AND Artificial Intelligence	101
Search string #3	DSS and Edge and cloud computing	Agriculture AND DSS AND (Cloud computing OR Edge computing)	78
Search string #4	Blockchain application in Agriculture	Agriculture AND (smart Digital sensors OR Technologies) AND Blockchain	86
Search string #5	Data governance and data security	Agriculture AND (Data Governance AND Data Security)	143

results from the Scopus database which was done on October 7, 2022. It was the main database used as it covers peer-reviewed publications from thousands of international publishers, including Elsevier. The search was done considering Title, Abstracts, and Keywords for each publication without limiting the publication duration. Most relevant papers were identified via reading the titles, abstracts, and conclusions. Complete review of the relevant papers was carried out for different focus areas (see Table 1) of smart agriculture. The literature review in this study was supplemented also with grey literature such as relevant project reports, online information related to the projects, and additional recommended recent literatures.

In order to address different focus areas, various subject specialists have participated in this review. The review work was followed by concept development to promote the integrated use of smart technologies and enhance smart farming [27]. The concept development was done integrating the results of literature review, experiences, and expertise from different aspects: digital sensors, data collection and analysis, application of AI, Data platform and BC, DSS, and data governance and security. The proposed concept has been further discussed along with its perceived implications.

3. Literature review

3.1. Major technologies for smart agriculture systems

Major digital technologies for the development and implementation of smart agriculture system include AI, big data, cloud and edge computing, smart sensors, IoT, BC, satellites and robotics [2,8,12,27]. AI is applied in smart agriculture using technologies such as machine learning and deep learning [28]. Machine learning is a crucial technology with different models that enable users to have effective DSSs. It enables farmers to make fast decision e.g. automating and optimizing water and soil management, crop disease detection, pesticide use, livestock management etc. [2,8,29]. Deep learning is being introduced in smart agriculture and used to process images and data and handle complex problems [30]. IoT links different objects through internet using smart technologies such as Bluetooth, wireless sensor network etc. and enables humans to efficiently control the linked objects [2,8].

Robotics are designed to mimic human movements and perform tasks. They are very important to perform some agricultural activities even under complex conditions. Cloud computing offers services such as cloud storage and access to data. To tackle problems related to centralized mode of cloud computing, edge computing is emerging as efficient data processing and it works in combination with IoT and cloud services [2,11]. Recently, cloud and edge computing techniques are widely being applied in smart agriculture e.g. for weather prediction and acquisition of agricultural data. Big data technology, with its advanced analytics models, operates on a massive data gathered from different sources e.g. ground and airborne sensors. With massive amounts of agricultural data, big data helps to make accurate predictions in smart agriculture. BC is a distributed digital ledger technology with a potential application in smart agriculture e.g. for developing more traceable agri-food supply chains [8]. The above mentioned digital technologies applied in smart agriculture operate using the built-in smart sensors [12].

3.2. Challenges in smart agriculture

Agricultural data is scarce and individual data makes the accounting of agricultural stocks and fluxes challenging, leading to uncertainties in agricultural performance indicators and the environmental footprint [31]. Even though the agriculture sector has been lagging behind regarding application of new smart technologies, especially at pre-harvest and post-harvest stages [32], in recent years, it is undergoing a new 'green revolution' triggered by the exponentially increasing use of information and communication technologies [33]. Regarding the digital transformation in agriculture and rural areas there are projects that assessed: implementation of sensors for crops [34,35]; dairy farming to improve decision making on farms [36]; food safety and security [37,38]; use of robotics and drones in crop production [39]; remote sensing [40]; analytics and communication technologies for agricultural sustainability [41]; open digital platform and network of digital innovation in agriculture [42,43]; and e-tools and good practices for e-governance to facilitate data and information flow [44,45].

Furthermore, the Copernicus program has enabled large amounts of free and detailed satellite imagery, which can be used to scale up data-driven solutions [46]. However, harmonization and pre-processing of the large data volumes are required before they can be used in large-scale agricultural applications, due to missing data, noise, mismatches in scales, scopes, and formats. Data of different modalities are often stored without being used and the integration and use of these data requires further investments and research [47]. Although there are many efforts to apply smart agriculture, there are still challenges that need to be addressed through additional research.

3.2.1. Problems related to isolated sensors and processing of multiple data sets

Off the shelf and fully integrated digital farm management systems are not yet available. This reduces the value of data generated from single sensors. Application of multiple real time data sources, multi-sensor data, and non-sensory data from third party organizations can help to create a more comprehensive data inventory. However, every additional data source will provide data in a different format, and in different time intervals, thus leading to the challenge of harmonising and processing groups of data. An integrated data platform enables the combined use of pre-processed data from different sources. To address this challenge, many advanced methods are built around data fusion that uses e.g. neural networks at the core [48]. Current digital systems also focus on different types of data (location, weather, behaviour and use of territory, yields, health, etc.), using different technologies to collect local data and create a network. Therefore, there is a need for integrated and cross-cutting methodologies to develop continuous and cost-effective real time monitoring tools with associated advanced statistical models, AI, and sensor-based techniques.

3.2.2. Challenges related to data-driven solutions for value addition when collecting data in agriculture

There is a significant emphasis towards the techniques of data collection aspects, while the practical use of the acquired data is often limited to basic threshold monitoring and trend reporting with less actual solutions to real-life problems [49]. Added values could be increased via applying novel AI and machine learning approaches and provide practical support for the farmers' decision making. Data value could be added through improving data accuracy, interoperability, data storage, computational power, and farmers' effective use of the data technologies. The new concept will enable smallholders to gain access to relevant data and services.

3.2.3. Increasing demand for use of digitalization in agriculture

Consumer and societal demand for higher quality food products and related information has increased [50]. For long-term sustainability potential and traceability, digitization of the agriculture sector should be promoted and integrated with training and awareness creation as well as effective information flow [51]. More development and application of digital tools is expected to increase agricultural productivity, sustainability, and reduction of food losses [52,53].

3.2.4. Data uncertainties in large-scale agricultural applications

End-user perspectives operating in isolation are insufficient for successful real-world big data applications in agriculture [49]. The proposed concept will apply a systems-based approach to co-develop integrated data solutions. This will require agricultural and big data expertise to engage in a holistic and interdisciplinary process, develop a common language to communicate effectively, and reduce the uncertainties and inconsistencies of multi-faceted farming systems.

3.3. Sensors and data generation and collection

Different agricultural data sets from, for example climate, soil and water, crop and animal, bio security, genomic, farm management and remote sensing are often segregated in "silos" [47]. The effort of harmonising and providing various data sources for advancing digitised farming has only started, with useful examples such as the FaST-EU Space Data for Sustainable Farming [54]. The application of smart technologies and the efficient use of agricultural data resources should be advanced through integration, storing, managing, and sharing of the data. Different data sources provide the data in different formats and at different time intervals, hence requiring harmonization of the data streams, e.g. interpolation, and different types of pre-processing to enable a combined use.

For instance, the continuous flow of earth observation data can be used to develop models that are responsive to phenological changes in variable weather conditions. The effective combination of both terrestrial and aerial platforms enables the combined use of very high spatial and temporal resolution data that can suggest optimal use of limited farm resources. Satellite images provide accurate information at a large scale that can be used to monitor the status of crops and animals, e.g., crop growth stage and yield [55]. There are also various DSS developed, based on satellite data, for example CropSAT, that provides vegetation index maps from Sentinel-2 data [56].

3.4. Application of AI on data integration and analysis

During this last decade different studies have been carried out to use data to interpret the past and predict the future and design DSS tools, through use of constant monitoring or specific big data science enquiries [57,58]. The increasing amount of agricultural data enables more accurate models of higher complexity leading to increased process understanding. This data-driven development has been demonstrated in many recent works, e.g., AI classification tasks, where state-of-the-art machine learning (e.g., deep learning) methods typically require larger amounts of data than classical model-based approaches.

Advanced methods are built around data fusion that uses neural networks at its core [48,59,60]. Data fusion techniques combine data from multiple sensors, and related information from associated databases, to achieve improved accuracies and more specific inferences than could be achieved by the use of a single sensor alone [61]. The biggest advantage of data fusion is the possibility to fuse multi-modular and heterogeneous data sets. Despite the considerable efforts taken by the researchers and software developers to create systems for comprehensive farm data analysis, there is still a lack of a unified, customizable and flexible solution [60]. It is hard to find a universal system which would be able to operate with different data inputs and would have flexible data processing options. The proposed concept aims to develop an enhanced data platform that can be considered as a decision-making tool with simple and fast data entry (manual or automatic) powered by flexible and detailed reporting.

3.5. Application of Blockchain technology

Recent research studies have investigated how to apply smart technologies such as BC and Smart Contracts for traceability and security of food products [62]; agricultural supply chain management, land registry and management, and agricultural insurance as part of flood impacts adaptation strategy in rural areas. Data and information are very important to promote the use of digital technologies and implement smarter farming approaches, increase agricultural productivity and sustainability and reduce waste of resources [27,62–64]. The ICT facilitates the data gathering, storage, process, analysis and use of data for timely decision-making processes [63]. However, the ICT does not avoid bias in the collection and use of data leading to less trust amongst different stakeholders that should use the data e.g. in the Agri-food sector. BC technology is an effective tool to avoid such bias through distributing the data management to a number of participants (e.g. network nodes), increasing transparency, and making data manipulation difficult within the BC environment [63,64]. The BC is an immutable distributed digital ledger. It provides a constant flow of credible data. In smart agriculture, as the number of inter-connected devices for information gathering is increasing, the complexity of data security increases. To address this challenge, it is important to develop a system that integrates the IoT system with the BC. This enables a more transparent, reliable, secure, and de-centralized data storage service and an automated and optimized management of agriculture systems [65]. The BC technology is an example of emerging technologies with huge potential to positively impact the agriculture sector, but it is energy-intensive and not well established and not widely applied yet in the agriculture sector. This BC enhances the generation, storing, governing, sharing, using, and tracing the relevant data resources and further advance the smart and sustainable agriculture in Europe.

3.6. Data governance and data security

Data plays an essential role in agriculture and application of one data source is insufficient for comprehensive analysis and optimal decision making. Application of multiple data sources, including multi-sensor data, data from third party organizations (e.g. climate and environmental data, mapping services) and historical data sets can help to create a comprehensive overview of the agricultural entity. Thus a data fusion method can be applied to combine data from various sources with the main aim to get more value from collected data.

Agricultural data and their use for better decision-making and innovation are at the core of the digital transformation of agriculture, but fragmented, not full and unclear data governance arrangements may decrease farmers' willingness to adopt digital solutions in their daily operations [66,67]. Data governance is considered as a set of processes, standards and guidelines that defines how the data assets are managed [68]. It involves establishing rules for data collection, storage, usage, sharing, and security to ensure that data is accurate, consistent, and trustworthy. Data security measures should include access controls, encryption, firewalls, antivirus software, intrusion detection and prevention systems, backup and recovery systems, and security policies and procedures.

3.7. DSS opportunities and challenges

The continuous flow of earth observation data can be used to develop models that are responsive to phenological changes in variable weather conditions. The effective combination of both terrestrial and aerial platforms enables the combined use of very high spatial and temporal resolution data that can suggest optimal use of limited farm resources. Satellite images provide accurate information at a large scale that can be used to monitor the status of crops and animals, e.g., crop growth stage and yield [55]. There are also various DSS developed, based on satellite data, for example CropSAT, that provides vegetation index maps from Sentinel-2 data [56].

However, there are problems related to digital systems such as limited knowledge of stakeholders, high costs of sensor networks to collect high spatiotemporal data, heterogeneity in grassland and arable crop, lack of available technologies for real-time *in-situ* crop and sward qualitative data measurement. Smart technologies can assess inter- and intra-field spatial and temporal variability in crop and animal production systems [69], but need to be developed and implemented with effective DSSs. The effective application of advanced smart technologies enables to perform real time observations and measurements of spatial and temporal variability. It can increase the economic competitiveness of farms, e.g., through reducing the labour requirement and repetitive tasks on livestock farms. As shown by Streefkerk et al. [70] seasonal forecast in combination with local knowledge can increase the resilience of rain fed agriculture during dry periods and support agricultural decisions. Similarly, DSSs are now available for use by grassland farmers for the purposes of crop, grassland and animal management [71]. Some DSSs have utilized algorithms to continuously train a model to simulate growth factors between measurement dates on pasture. Also a fully transferable DSS for crop irrigation was developed by Bonfante et al. [72]. DSS have several components, and one of the most important is the graphical user interface, which is the communication between the system itself and the end-user [73]. However, farmers' acceptance and uptake of DSS is still relatively low [74] and multiple factors that restrict the wider implementation of DSS. This may be because farmers do not necessarily have knowledge of sensors, ICT and data management and analysis [75]. Moreover, DSS are used Farmers need to adopt a different mindset towards these systems, and there are multiple factors that restrict their use of DSS, such as the performance of the system, its ease of use, trust in the DSS output, and the system cost makes farmers critical towards the acceptance of DSS [76]. Next to that farmers need to adopt a different mindset towards DSS, when implementing a system, a participatory approach is need to successfully implement these farmer supporting systems [70,75].

4. Concept development

4.1. General overview of proposed concept

Based on the literature assessment, the concept depicted in Fig. 1 has been proposed for an integrated smart farming system. In this system, the information from different sources including earth observation is managed to enable the efficient and sustainable use of resources. The concept is structured into five blocks: (I) agricultural systems (at local, regional, and global levels); (II) data sources (real-time sensor data from the agricultural system, historical data, and open science data together with input from the users); (III) the data platform; (IV) data sharing; and (V) Blockchain. Three phases are included in the concept: real-time data collection from the system using different sensors; data integration and analysis; and application by data sharing and upscaling to regional and global levels to be used by stakeholders. Processed data could be shared with stakeholders via different interfaces, platforms, and BC which can also facilitate closing the feedback loop with the farm by performing direct refinements or providing new input values for the data platform.

The concept focuses on different levels of smart agriculture and apply upscaling for the approaches developed, starting from the local farms with vast amounts of local data of the highest detail, which could also be applicable at the regional and global level by connecting Earth Observation data and remote sensing methods at various levels. This provides opportunity to monitor at farm level energy consumption and emissions levels, to comply with European environmental standards and minimise the ecological footprint and maximise biodiversity.

4.2. Data collection methodologies

The conceptual system monitors and assesses local variables of farming systems (livestock, both indoor and outdoor), crops and horticulture farming, including weather patterns. The data collection covers different entities, objects and sensors to be used for real-time on-farm data collection in combination with historical data. Smart sensors and their combinations could cover desired use-cases and demonstrations. End user and stakeholder inputs are also considered as valuable inputs. In addition, earth observation data from satellites and drones can monitor the large-scale and local processes. Sufficient and relevant data could be generated from local sensors, drones and satellites together with monitoring devices used for farm, livestock and environment monitoring.

Within the concept, different sensor systems are evaluated, and some could be selected for inclusion to the data collection activities. In the first phase, in a co-design, smart sensors, pertinent variables and data communication could be determined. The IoT integrated sensors also need to be evaluated, installed, and managed. Moreover, the frequency of measurement can be determined in line with the information need from animals, crops, grass trees' perspective in relation to the environmental conditions.

In the concept, a mobile smart platform is central, where sensors could be included for data collection at the farming level. The sensors are connected to the IoT networks to provide high spatial and temporal data of different variables. Earth Observation could be used to provide continuous monitoring data of the farms at different scales. The concept uses airborne platforms e.g., drones with LiDAR or optical sensors to collect multi-variable and high-resolution spatial data. Drones can be equipped with weatherproof sensors to ensure data collection in all weather conditions. Furthermore, satellite data from optical (e.g. Sentinel-2 and Landsat 8/9 (10–30 m every 5 days) and radar sensors (e.g., Sentinel-1, NISAR, ALOS-2 PALSAR-2) proved wall-to-wall coverage,

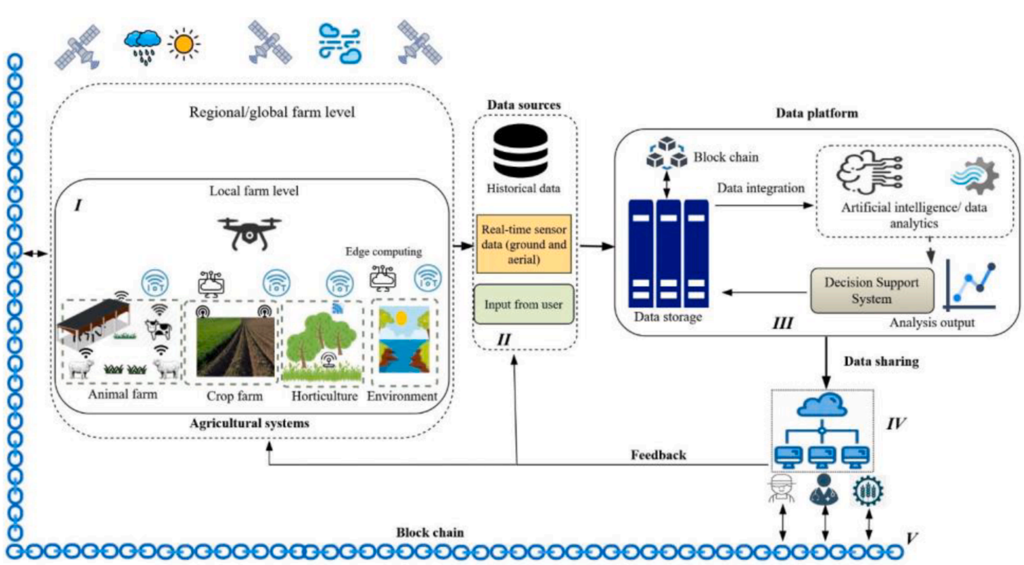

Fig. 1. Overview of proposed concept with agricultural system (I), data sources (II), data platform (III), data sharing (IV) and Blockchain (V).

and high resolution images from World View and Pleiades can rapidly provide additional information at higher resolution. In order to make more comprehensive models, open data sets available on open-access repositories [77], national open data services (current and historic data of meteorological, environmental and farming variables) or Copernicus datasets [78] could be used.

The concept explores the combined use of satellite images with high-resolution drone imagery (resolutions of approximately three centimetres) in super resolution the AI algorithms to get very high-resolution data from the entire satellite covered areas. The collected data (by the project and open data sets) will be delivered to data analysis. For the data analysis and DSS model development historical data from the target farms will also be used. Examples of the available data to include: metadata on sites, grass growth data, grass quality data, animal performance data.

4.3. Data platform

The data analysis and transformation process take place in the remote data platform specially built for data fusion and processing purposes. The data platform could include various mechanisms and approaches for diverse and comprehensive data analysis including the AI and advanced statistical algorithms. Important features from the datasets could be extracted and fused to deliver the best inputs for decision-making scenarios. The data platform contains several interconnected components, including data integration pipeline, DSS and business models. These components could be used for supplying valuable insights and knowledge for the end users and stakeholders enabling efficient farm management and operation, evaluation of the effectiveness of the resource consumption, policy making and ecosystem monitoring on global scale.

The data platform is considered as a scalable system (see Fig. 2) for distributed and flexible processing of different agricultural, livestock and environmental object data. The data platform acts as an intermediary between data providers (various measurement systems and data sets, historical data, available on other data platforms) and data consumers (reporting, modeling and third-party systems), and provides customizable facilities for organizing data storage (such as data warehousing), processing and analysis pipelines and result sharing. A unified agricultural object data platform could be used for decision support, data analysis and process optimization. Existing systems, open data sets and available on-farm generated data can be combined and fused to the integrated platform. Information and DSS tools will be designed to be accessible and understandable for farmers.

A data platform acts as an integration layer between data sources, processing algorithms, and target data consumers. It provides flexible orchestration tools for running various components for the platform in a unified manner. The integration engine provides scalable infrastructure for storing incoming (raw) and already processed data, including essential metadata. An important aspect of the data platform is data governance. Ensuring the controlled and appropriate access to the sensitive data is essential for successful cooperation with external stakeholders. Batches of historical and pre-collected datasets and real-time streams from IoT devices are considered as primary data inputs to the data platform. Various types of data processing frameworks are supported by the data platform, including low level data sanitation and error filtering up to the more sophisticated business and AI/machine learning models and decision support components. Data processing results are supplied to data consumers in form of reports and analytic summaries, categorised data marts or as exported/shared data sets.

Within the concept, the data platform could be established as a cloud-based data storage and processing unit with capabilities to combine different data sources including systems and available on-farm generated data. The proposed platform follows best practice in distributed and asynchronous data processing by utilising multi-agent techniques in conjunction with real-time data warehousing.

The proposed concept provides an approach for successful data fusion within the farm using different data sources: (a) Data from on-site farm management systems, including long-term observations), wearable sensors for plant (e.g. sap flow to estimate transpiration) and livestock (i.e. sensors to collect welfare and health information); (b) External data sets (including remote sensing information, historical data sets and environmental monitoring); (c) Farmers' input and specific knowledge. All data gathered can be fused in the data platform, providing standardised data exchange interfaces for stakeholders to support decision making. This may have a positive effect by increasing data efficiency, reducing analysis time, and costs.

4.4. AI application for data integration and analysis

The AI models along with statistical techniques can extract information and patterns from the sensor data and detect phenomena. In the proposed concept the AI methodologies can provide a framework for feature/metric selection to reduce the number of dynamic variables from pre-processed sensor data. Development of analytics and machine learning algorithms enable asset state (farm) prediction for a given input

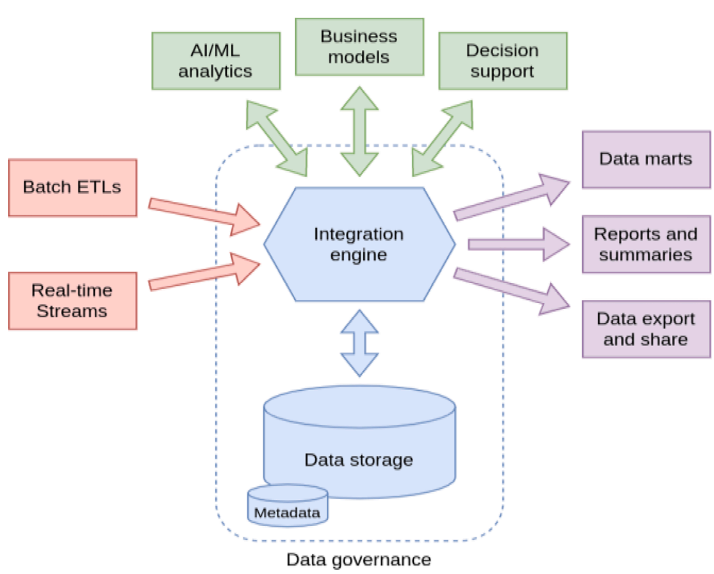

Fig. 2. Conceptual illustration of the data platform.

state (Fig. 3). The outputs of these models can be validated using the sensor data. In this context, the historical and data collected through the sensors on ground, aerial sensor, and satellite data can be used for training of the AI models. The output of digital data processing and integration models could be utilized to the actual farming system. Therefore, the validated models could be robust enough. In this context to analyse the obtained information from different sources descriptive analytics, diagnostic analytics and predictive analytics with the possibility to forecast future phenomena in different farming situations can be developed. Forecasting dynamic models could be developed to predict crop dynamics, like seasonality and trends. Selection of the most adequate land surface dynamics model will be done e.g. by means of the Q test of Ljung-Box, and the Schwarz and Akaike information criteria. The accuracy of the forecasting procedure can be evaluated to improve the performance of the developed models in the proposed concept.

4.5. Edge and cloud computing

Within the proposed system, two computing paradigms will be evaluated. Where feasible edge computing could be used to reduce latency and provide more processing of data closer to the farm, as a data provider [79]. Application of edge computing involves placing of service provisioning, data, and intelligence closer to users and monitoring devices. Benefits of edge computing can be seen when computing and making analysis of real-time data. One of the motivations for edge computing is use of data intensive sensors and the need for fast response times from the farmer e.g., audio and video monitoring of animals, pests, or weather extremes such low temperatures or rainfall events affecting crops. Significant volumes of the data should be processed before obtaining the value of the monitored variables, as well as alerting the farmer to appropriate (even rapid) action if an anomaly is detected, especially if animal health or mobility or crop health is affected.

Another motivation to apply edge computing in precision farming is related to data privacy and security [80]. Farmers are usually not willing to share the details about their farming processes due to business specific knowledge. In this case edge computing provides a compromise where the farmer can implement own data processing pipelines without sharing implementation details, while still being able to exchange information with cloud infrastructure.

In most of farms, there is little need for decisions to be made in real-time when each millisecond is crucial, thus another paradigm of cloud computing can be made applicable. Within the proposed concept open-source platforms can be evaluated, compared, and further adapted as required. Cloud and edge computing need not compete but can be employed selectively. Within the proposed concept, functions which can be handled by the computing split between the end device and local network resources will be done at the edge, while big data applications that benefit from aggregating data from everywhere and running it using different analytics approaches and machine learning algorithms will stay in the cloud.

4.6. Application of Blockchain technology

In order to avoid malpractice and ensure trust and transparency in data handling and sharing, BC technology could be a robust and effective option [81]. This will provide a tamper-proof and immutable data storage mechanism for critical data sources and a constant flow of credible data. Smart contracts could be designed to run the events accordingly to form a reliable agreement model for the system. With data on a BC, the system will build different analysis models based on the need of the respective farming model, incorporating smart contracts for monitoring and control. For large volume data, distributed data storage mechanisms need be integrated with BC [82,83]. In the concept, the application of BC could enhance the business contracts with high standards of trust amongst trade partners as well as product traceability due to the advanced and reliable data/information processing and sharing system.

4.7. Decision support system

The main purpose of a data platform is to provide decision-makers with accurate, timely information needed to make the right choices and decisions. Therefore, the development of the DSS is a crucial part of the proposed concept, as success of the data analysis can be evaluated by the effective application of the proposed decisions to the end-users. The main task of a DSS is to assist the end users and stakeholders in decision making and it aims to improve the overall farm‘s operation and management processes [84]. The DSS itself does not make decisions in isolation, rather it provides several alternatives to choose from. It should be emphasized that the end user is the main decision maker and is responsible for the actions taken. The process of the DSS operation will involve combination of data from various sources (sensory data, farmers input, crop, animal data, etc.) that might be analyzed and run through a collection of models (statistical, machine learning, etc.) allowing to better understand solutions for a specific farm related problems (e.g., management of water resources, low-input farming, management of

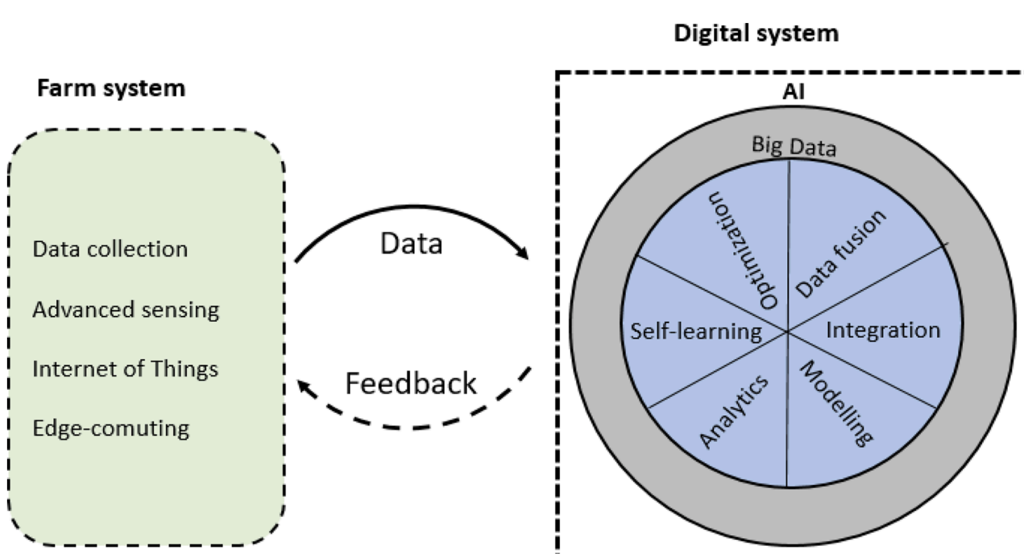

Fig. 3. Concept of data analysis approach for smart farming.

grazing plans, improving livestock performance, health and welfare, increasing crop yield, environmental condition). Therefore, the data to be analyzed need to be retrieved, stored and organized in a way that facilitates decision making for the specific contexts.

The DSS will also provide a user interface (UI) that is an intermediary between the system and the end user. In general, the UI can be implemented in various forms (e.g., command line, UI with graphical elements) and highly depends on the end user's needs. Therefore, the UI within the proposed concept considers the end users' technical skills and competences, together with the integrated BC technology allow for transparency, security and easy understanding of processes which create trust in the DSS. The DSS to be developed has different parts that support various decisions based on data analysis. For example, grassland management decision support for the farmer and tools to make decisions about animal health, welfare, and/or reproduction [85]. Effective use of the DSS can be contributed to more sustainable and resilient farming systems across a range of climatic conditions.

4.8. Governance and data security

The Governance systems proposed in this study can ensure consistent, reliable, and accurate data for: farmers - for management and decision making purposes; the actors in agri-food supply chain - for assurance, marketing and payment purposes; and Government agents- for proving the delivery of “public goods” for environmental farming schemes. It enables development of a unified agricultural object data warehouse that can be developed and used for DSS along with solutions for data analysis and optimization. The data warehouse will act as an intermediary between data providers and users to provide customizable facilities for data storage, organization, processing, analysis and sharing the generated knowledge. The proposed system promotes the design and deployment of robust systems to ensure that farmers' data is used ethically and appropriately with agreements from the participating farmers regarding data use. These systems will be designed to be scalable as the volume and sources of data increase [86].

5. Discussion

5.1. Data valorization

As climate change is generating significant interest in the development of specific tools and models adjusted for each type of crop and land-based livestock, the proposed solution enables users to rectify one of the bigger disadvantages of advanced machine learning techniques e.g., deep learning applied in various agriculture fields such as discontinuity and non-integrated data. The application of the proposed concept could generate accurate and reliable farm management information from the integration of different data sets, by receiving real-time and continuous information on selected variables. For instance, in recent years, big data was generated in various parts of Europe, but was specific to the site, crop, or research program theme. Attempts were made to aggregate these data and present in a friendly form for the users (farmers, researchers, government officials, business and other related stakeholders) but are still far from general use and valorization. A data warehouse concept along with integrated AI and analytic models, which is a new way of doing smart and digital farm management systems could deliver a robust solution in this regard. As a result of this farmers can be able to make decision-making scenarios easier, which will result in the resource and cost reductions from the farming and technology providing sides. The system enhances data warehouse concept with all the specific features and methods/ algorithms and tools for valorising the historical data, working with them, and responding to the present and future challenges and opportunities in farming systems.

There are also added benefits due to the fact that the integrated data set and digital solution tools will feature high-resolution models co-designed with the user data, spatial fields data and data derived from satellite. The historic data in combination with real-time environmental monitoring and farming systems creates new data streams. The reliability of integrated data use might be increased due to the development of models based on remote and ground-based datasets covering climate, meteorological, environmental and farm conditions. Efficient use of farm data increased due to the development of algorithms for processing the Earth observation data to enable estimation of variables or parameters required in the DSS. Broader adoption of improved monitoring and DSS systems, based on quality data, will also provide better decision-making, not only for farmers but will also serve as a basis for policy makers.

5.2. Farm productivity and competitiveness

The proposed solution could enable the generation of new data, knowledge and practices in agri-food systems supported with advanced smart technologies. This will lead to increased competitiveness of smart farms through improved profitability, environmental sustainability, and social acceptability. Multiple benefits such as farm productivity, competitiveness, product quality and safety, health and welfare, best practice, traceability of products and consumer acceptability will be increased. The farm management can be improved by applying integrated, cross-cutting and multi-actor approach methodologies; emerging digital technologies; data generated using smart sensors (including both, ground, and aerial (drones and satellite); and advanced statistical models and AI models. Productivity, resilience, competitiveness and environmental performance of crop, horticulture and livestock farming can be significantly increased by the provision of low-cost and reliable novel hard- and software, data analysis, smart sensors application and optimized precision farming management practices. The new solution can also create training opportunities for farmers, practitioners, and professionals and increase scientific knowledge base on smart farming systems in order to enhance the productivity and competitiveness of smart farm systems.

5.3. Effective monitoring of farm operations and decision making

The continuous monitoring of real time data and integrated use with the historic data in combination with newly developed models will improve the understanding of environmental processes and farming practices. In addition, as there is limitation of data management system across spatial and temporal resolutions, the unprecedented spatial and temporal process could lead to novel scientific knowledge and sharing it [87]. The advanced AI-based techniques and complementary management support systems enhance process understanding, smart farming systems and allow better estimation of uncertainties. As a result, it is possible to develop novel farm operation practices and monitoring which allow for more efficient use of resources (e.g., energy, water, soil, nutrients and pesticides, fodder, labour, investments, etc.) and targeted interventions when needed (e.g., pest control or veterinary). Continuous measurements of environmental variables and animal health, welfare, reproduction and productivity can play an important role in enhancing transparency, traceability, and monitoring along food supply chains, adding value for producers and consumers alike.

The proposed solution brings together important work tools needed to make real-time decisions. It can contribute to optimal decisions in critical conditions by providing timely, high resolution and up-to-date information. It processes data from ground sensors, drones, and satellites, bringing complete identification of phonological stages, real-time pests and diseases pressure, plant and soil nutrients correlated with the data taken from the local weather stations, according to a customized algorithm on crop species to be analyzed.

5.4. Farm business models

The development of cutting-edge digital technology for monitoring farm productivity, animal health and welfare places smart farms at a competitive advantage, opens business opportunities for manufacturers and strengthens the agriculture sector as business options for new generations. The proposed solution has the possibility to design farm business model (FBM) frameworks (upscaling) for trusted third party industry organizations and act as trusted data brokers. For example, the innovative FBMs could create values through: (i) Strong Networking- by facilitating the formation of novel networks of farms empowered with advanced digital tools (smart farming). Farm networks enable farmers to mobilise and use the resources collectively with focus on profitability and sustainability of farm systems [88,89]. (ii) Increased accessibility to data resources- by developing systems for resource sharing as well as accessibility and efficient use of resources (e.g. data, smart tools, and other resources) for farmers and other stakeholders. (iii) Increased inclusivity- by enabling all stakeholders to have fair and guaranteed representation in decision making, specifically for farmers. (iv) Adaptive Marketing system- by creating a new way of marketing of agricultural products that can benefit farmers and consumers [90].

Due to their potential advantages, climate-smart agriculture and digital technologies are attracting more investment in recent years. The proposed solution can take smart agriculture beyond the state-of-the-art creating favourable conditions for innovative FBMs. However, there is a knowledge gap regarding the profitability of the increasing investments in smart agriculture [91]. Application of the proposed solution enables to examine the innovative FBMs using integrated cost-benefit analysis (CBA) approach to evaluate the financial profitability for farmers as well as the environmental and social benefits to the society as a whole [92,93]. The CBA enables capturing the 'true' cost and benefits (e.g., broader human and livestock welfare effects) including externalities (Garnett et al., 2018; [94,95]).

5.5. Sustainability of smart farming systems

Climate changes, market approaches, demand for healthier products, and labour force depletion in agriculture have increased pressure to the agriculture industry. Agricultural production faces challenges such as climate variability, land degradation, loss of ecosystem functioning in combination with an increase in global population and dietary changes. Agriculture generates significant negative environmental impacts, and, at the same time, the sector is vulnerable to short term weather phenomena and long-term climate change [96]. Changes in climate, in average temperatures and rainfall, together with the increase in extreme events in the short and long term, are already affecting crop yields around the world. To avoid possible losses, it is necessary to provide 'early warning' information to farmers. Climate change mitigation and adaptation have been a global challenge for this generation [97]. The application of the ICT elements in agriculture gives the chance for paradigm shifts at the farm, processor, logistics, and consumer levels [98].

The proposed concept enables more efficient use of resources, promotes the economic competitiveness of farmers, protects biodiversity and mitigates climate fluctuations. It harnesses digital and geospatial technologies to enable the re-design of agricultural systems with increased sustainability performance [53]. It improves farming operations such as planning and management of crop and animal production through more efficient use of resources (material and human) and open access to digital data and tools (multi-actor platform, DSS).Through the development of a multi-disciplinary, multi-stakeholder, whole-farm approach, it is possible to significantly increase production efficiency, resource utilization and animal welfare whilst reducing emissions, and thus improve competitiveness, environmental performance and public image of agricultural farming. However, with the implementation of the concept, further study is required to evaluate the environmental and socio-economic performance considering material and economic flows not only from the aspects of agricultural activities but also the aspects of major technological solutions and related infrastructures such as the IoT, BC, remote sensing tools, and DSS platforms. The sustainability of smart farming systems with advanced data integration and real time processing could be evaluated using a life cycle analysis approach while considering smart farm systems at local and regional levels [99]. This could lead to more efficient use of the local on-farm and regional resources (optimizing grazing calendars, improving crop rotations, increasing the on-farm feedstuff production, pasture yield, reducing feeding inputs, etc.) [100].

5.6. Increased resilience of farming systems

The proposed concept could increase resilience of farming systems by managing current status and forecasting future events. Based on the data and modeling outcomes, unplanned events can be anticipated which will increase the resilience of farming systems. It enables farmers also to diversify their production systems by adopting more sustainable farming practices. The integrated data set, DSS with options of edge and cloud computing, multi-actor platform, on-line management tool, and the farm business models enable long term positive impacts.

The proposed solution allows to accurately accounting the different stocks and fluxes of a farm system allowing to considerably reduce resource demand and wastes in both small-scale and intensive farming with direct impact from different aspects, e.g., water and energy resources, nutrients, land use, above and below ground biodiversity, and GHG emission. Creating data from farm impact assessments and operational monitoring available to public authorities may reduce the need to carry out additional environmental monitoring saving public financial resources. The enhanced transparency of the operational conditions of farming could help rural communities to make informed decisions on issues that affect their neighbourhood or their livelihood. The newly developed, innovative smart technologies can be applied to the broader agricultural sector [101]. This will give many opportunities for technology providers, to create high value jobs and develop new market products based on digital solutions. All measures and integrated smart technologies could directly contribute to traceability and increased consumer acceptability of food products. Farmers can provide well-priced products with increased food quality and safety contributing to sustainable Farm-to-Fork (F2F) strategies. For instance, in the F2F under the European Green Deal, Europe desires an increase in environmental standards as well as the efficiency of food production as part of the Commission's agenda to achieve the United Nations' Sustainable Development Goals [101,102].

Effective information flow enables the achievement of multiple benefits for animal and crop productivity, competitiveness and best farm practices which could contribute to the future of the agricultural sector. Productivity, resilience, competitiveness and environmental performance of smart farms can be superior to conventional ones [96,103]. Meanwhile, production costs, feedstuff purchase and GHG emissions will be reduced, increasing complementarity between crop production and livestock [100].

The implementation of the proposed concept could face some challenges: (I) The gap that sometimes exists between the farmers and the technology providers in terms of explaining the information relevance, usefulness, reliability and ease of use; (II) Resistance of the older generation of farmers who have more difficulty to adapt to the use of new digital technologies, new sources of information; (III) difficulty to move from partitioned systems to an integrated approach; and (IV) unexpected restrictions on uptake of novel digital technologies by regulatory environment; cost of the new technologies. In order to further strengthen the resilience of smart farming systems, the above mentioned challenges and other potential barriers should be identified during implementation and performance evaluation of the proposed concept and further investigated in post-ante studies from different aspects contributing to the transition to sustainable food systems.

5.7. Limitations and future scope of this study

In this study, there is a limitation due to the fact that there could be some papers and documents not captured in the review part. Although the major digital technologies for smart agriculture have been discussed briefly, the limitations of each technology have not been covered. The practical development and testing are out of the scope of the study. Future studies will include the design, test and practical demonstration of the proposed concept with its major features. The application of smart digital technologies for efficient collection, handling and sharing, integration and analysis, and governance of agricultural big data will be studied in detail. The future scope includes also a detailed assessment of sustainability performance of the proposed concept and related innovative farm business models.

6. Conclusion

Agricultural business sectors can harness the benefits of smart technologies and increase their productivity to meet the needs of a growing human population and tackle the existing challenges such as climate change, loss of biodiversity and other environmental issues. However, there are challenges to understand and efficiently use different types of agricultural data from multiple sources and not integrated. This paper presents the concept proposed to facilitate the full integration of digital technologies to enhance future smart and sustainable agricultural systems. The proposed concept enables capturing real time agricultural data, integrating and managing data from multiple sources using novel agri-tech solutions, using AI, building governance systems that manage high volumes and multiple sources of agricultural data, and developing a digital DSS for farmers and a range of industry stakeholders.

In this work, literature review and concept development approaches have been used. Firstly, a comprehensive literature review was conducted to investigate the state of the art of the adoption of smart farming through the use of integrated digital data and sensor-based systems through participation of different experts. Secondly, the proposed concept was theoretically developed based on the results of literature review, experiences, and expertise from different aspects: digital sensors; data management; application of smart technologies such as AI, IoT, and BC; DSSs; data governance and security; and sustainability analysis.

The proposed solution has the potential to provide: a data collection method, a data handling and sharing platform, an AI application for data analysis, edge and cloud computing, DSSs to facilitate decision making process, application of BC, and a governance and data security system. Implementation of the proposed concept has the potential to deliver significant positive implications as it could improve valorization of agricultural data; farm productivity; farm monitoring and decision-making ability; and innovation in farm business models. It could also lead to increased environmental and economic performance, thus contributing to an overall increase in the competitiveness, sustainability, and resilience of the agricultural sector. The detailed studies on practical development and demonstration of the proposed concept and its sustainability performance will be future research directions of this work. In the short term, this study will benefit the researchers and developers of smart tools while in long term it will be useful for researchers, practitioners, and policy makers supporting the transition to smarter and more sustainable agriculture systems.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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