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Application of Agricultural Information Systems Development Kit for Multimodal Agricultural systems

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Abstract – Multifunctional and diverse agriculture has the potential to effectively address conflicting demands and requirements by concurrently boosting biodiversity, production, and provision of environmental services. Digitalized technology can assist in the creation and control of agricultural models and systems that are resource-efficient and adaptable to their environments. In order to demonstrate the potential of digital technology in promoting decision-making processes that prioritize diverse and environmentally sustainable farming practices, we present an analysis of Agricultural Information Systems Development Kit (AISDK). The AISDK was developed through a comprehensive literature review to identify the limitations of current tools. Additionally, in collaboration with stakeholders, we established the criteria for a decision-support tool that is based on knowledge. The findings of the review emphasize the ongoing challenges associated with the integration of multiple spatial, temporal, and sustainability dimensions, as well as the promotion of effective collaboration and communications among farmers and key stakeholders in the agriculture sector.

Keywords – Agricultural Information Systems Development Kit, Multimodal Agricultural Systems, Digital Agricultural Tools.

I. INTRODUCTION

The agriculture industry faces a multitude of challenges, including but not limited to food security requirements, market disruptions, the need for sustainable energy solutions and transitions towards a bio-based economy, achieving climate neutrality, and mitigating severe environmental impacts. The potential conflict between the availability of biodiversity and ecosystem services (ESS) and the productivity and profitability of crop cultivation arises from the intricate interplay of competing forces and demands. Diverse agricultural models and systems, which are formulated to boost environmental multi-functionality are believed to have the capacity to address a wide range of objectives, particularly at the landscape level. These systems achieve this by simultaneously providing various amenities and supporting biodiversity and ecosystem health and resilience. The design and implementation of agricultural landscapes are faced with significant challenges due to the diverse array of social, economic, political, and environmental factors that exert influence on these systems. Nevertheless, the utilization of digital technology enables farmers to gain novel perspectives on agricultural decision-making and successfully reconstruct agricultural systems within their specific geographical context.

In recent decades, there has been a notable increase in the adoption of digitalization in the agricultural sector. This has resulted in the emergence of numerous new technologies that are readily available to both academic researchers and professionals in the agricultural field. The utilization of various technologies such as in-situ and remote sensing, AI, digitally controlled machinery, and digital communication systems and data collecting platforms has facilitated researchers in gaining a deeper understanding of agri-food value chain and agro-ecosystems, as well as enhancing their ability to manage and monitor these systems. Decision Support Systems (DSSs) are increasingly becoming more comprehensive in order to address the requirements of communication and data sharing, as well as to meet the expectations of a wide range of stakeholders. The primary objective of DSSs is to collect and analyze data with the purpose of providing guidance for making informed decisions in farm management.

Approximately 80% of the surveyed farmers reported utilizing a variety of widely-used information and communication technology (ICT) devices, such as basic phones, cellphones, radios, televisions, laptops, tablets, and desktop computers. Approximately 10% of farmers have utilized or possessed a computer, smartphone, or feature phone, while a significant majority (80%) have utilized or possessed basic phones and radios (with rates of 67% for women and 71% for men). According to the data presented in **Fig 1**, it is observed that a significant proportion of female farmers (12%) and male farmers (13%) lack access to any form of information and communication technology (ICT) within their households.

Additional analysis of device ownership and usage based on gender and age unveiled that there was no significant disparity between male and female farmers in terms of owning and utilizing various devices. However, it was observed that younger farmers, specifically those aged 45 years and below, exhibited a higher propensity to possess and employ information and communication technology (ICT) devices compared to their older counterparts, who were above the age of 45.

As a consequence, the majority of individuals possess and employ solely radio and basic telecommunication devices, with approximately 20% of agricultural workers reporting a lack of ownership or usage of mobile phones. The proportion of males who possess and utilize a rudimentary mobile phone is significantly higher in comparison to the proportion of females who engage in the same behavior (62% versus 3%). In a similar vein, the data reveals that 37% of females, in contrast to 21% of males, indicated a lack of access to any form of telecommunication device. These findings have an impact on both the potential and actual scores. The UR score of smartphone-based extension is undeniably influenced by the limited adoption of smartphones.

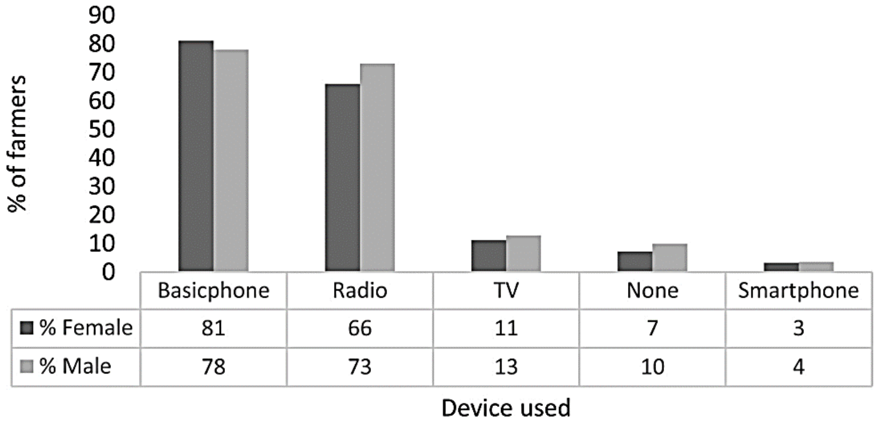

Fig 1. Individuals who use digital devices on a regular basis, with a frequency of at least once every 30 days. The study had a sample size of 690 participants.

The objective is to utilize synergistic effects to explore novel learning prospects within the agricultural information systems development. This is in response to the convergence of digital agriculture with conventional decision-making approaches, which presents fresh sustainability-related challenges. The future Agricultural Information Systems Development, which encompass essential perceptions for enhancing interaction and communications among diverse stakeholders in the agriculture industry for the purpose of the process of innovation, acknowledge the significant role of digitalization as a key concern. This phenomenon can be attributed to the indirect facilitation of novel partnerships and opportunities for experimentation within the broader society, as well as the direct transformation of the interrelationships, transparency, and management of agricultural information and advisory networks.

The article highlights the significance of multifunctional and diverse agriculture, emphasizing the utilization of the Agricultural Information Systems Development Kit (AISDK). This framework is distinct and focuses on integrating data in a systematic manner, utilizing digital technology to enhance complex decision-making processes. The fundamental needs that underpin the development of the AISDK were identified and elucidated through a process of iterative discussion with stakeholders and consortium members, as well as a comprehensive analysis of existing literature on digital agricultural technologies. The rest of the article is organized as follows: Section II describes the methodology that has been employed in this article, which Section III review the relevant texts related to the research topic. Section IV presents the results and discussion of iterative process to institute AISDK requirements, designing AISDK proof of concept and architecture, requirement of AISDK, and a literature review on digitalized agricultural tools. Section V presents a discussion of the limitations of the research, as well as AISDK's future scope. Finally, Section VI draws final remarks to the research.

II. METHODOLOGY

The initial step in the development of the AISDK involved the identification of specifications for a novel tool. This tool aimed to facilitate the integration of biodiversity and ecosystem service provision into decision-making processes. Additionally, it was designed to align with the advancements in digital tools within the scientific and commercial domains. The identification of the essential criteria was achieved through a process of iterative communication with relevant stakeholders and consortium members. Additionally, an analysis of existing literature was conducted to ascertain the limitations of currently available technologies. Given the limitations, we formulated the theoretical and practical framework of the AISDK and developed a preliminary demonstration in the shape of a scenario illustrating the establishment of grassland buffer patches.

III. LITERATURE REVIEW

Throughout the course of its existence, the agricultural sector has undergone a series of transformative revolutions, resulting in remarkable advancements in productivity, profitability, and efficiency. To ensure the sustained ability of agriculture to meet the global population's needs in the future, industry experts anticipate the emergence of a "digital agricultural revolution" within the coming decade. Digitalization will have an impact on every component of the agrifood supply chain. The optimization of resource management can be achieved through the implementation of personalized, intelligent, and predictive strategies. The operation will be characterized by real-time connectivity and data-driven processes. Enhancements in traceability and coordination across value chains are expected to reach a level where precise management of individual farms, crops, and animals can be achieved based on their specific requirements. The utilization of digital agriculture is anticipated to result in the development of agricultural systems that exhibit high levels of productivity, proactivity, and adaptability, particularly in response to various disruptions such as climate change.

Consequently, this could potentially enhance the aspects of food safety, profitability, and longevity. Digital agriculture possesses the capacity to make a significant contribution towards the attainment of the Sustainable Development Goals across various domains. These include economic development, wherein it can enhance agricultural productivity, cost efficiency, and create new market opportunities. Additionally, digital agriculture can foster social and cultural development by improving communication channels and promoting inclusivity. Furthermore, it can aid in environmental development by optimizing resource utilization and facilitating adaptation to climate change. While there is a strong argument in favor of digitizing the agrifood sector, its implementation would necessitate significant transformations in agricultural methods, rural economies, communities, and the management of natural resources. Achieving optimal benefits will pose challenges and necessitate a systematic and thorough approach.

Digital agriculture, also known as the utilization of digital tools and technologies for the purpose of managing agricultural systems and making informed decisions regarding value chains, has gained significant traction in Africa [1]. This can be attributed to the rapid progress in technology and the growing accessibility of diverse digital tools and technologies. Digital agriculture encompasses various components, such as market and financial access tools, activity registration, and advice services. The prioritization of digitalization has been recognized by the African Union as a key focus in order to achieve the ambitious goals outlined in its Agenda 2063 [2]. According to McCampbell, Adewopo, Klerkx, and Leeuwis [3], various African governments have implemented policies to support the advancement of digital agriculture, such as Rwanda's ICT for Rwandan Agriculture Policy in 2017. There has been a noticeable trend among donors to allocate an expanding proportion of their resources towards digital agriculture, as evidenced by a rise in expenditure. According to Smidt and Jokonya [4], there has been a significant increase in the adoption of digital technologies among registered farmers, with an annual growth rate of 44%. This finding highlights the remarkable expansion of the digital agricultural sector in recent years. Increased attention leads to heightened scrutiny of outcomes and the imperative to effect substantial change.

Slimi, Prost, Cerf, and Prost [5] focused specifically on digital agricultural extension as one aspect of digital agriculture. This study examines the present capability of African farmers to effectively utilize and adopt autonomous extension tools and technologies, with a specific focus on phone-oriented services. Digital agriculture extension technologies encompass various tools and systems that serve to provide or enhance agricultural extension services. These technologies integrate pests and disease diagnosis tools, soil control decision support systems, and agricultural information sharing tools. The conventional method of "analogue" extension may be fully substituted by digital extension, although there is also the option of employing hybrid models that integrate digital tools with traditional approaches (such as face-to-face extensions). According to [6], digital extension services have the potential to yield various benefits, including enhanced agricultural productivity, reduced pest and disease incidence, enhanced comprehension of soil health conditions, and an overall improvement in quality of life. Due to their capacity to enhance connectivity and transparency among individuals possessing pertinent practical expertise, these technologies are also perceived as potentially disruptive.

Saçtı and Dellal [7] have argued that the significance of actual usage and current utilization is exaggerated, despite the ongoing enthusiasm and claims surrounding digital technologies in the field of agriculture. As an illustration, it has been reported that certain interventions, namely Smart Nkunganire in Rwanda and E-Soko in Ghana, purportedly achieved a wide reach of over a million farmers. However, it is worth noting that only approximately 42 percent of the farmers who enrolled in these digital agriculture services actually utilized them, as indicated by Abdulai, Kc, and Fraser [8]. Several studies have identified various obstacles associated with the implementation of phone-based services. These challenges include limited effectiveness, inadequate infrastructure, inappropriate information and communication technology (ICT) policies, and insufficient user capabilities. The existing body of research suggests that the evidence supporting the effect of autonomous interventions in agriculture in Africa is primarily based on anecdotal accounts. Consequently, our comprehension of the transformative potential of digital extension in this context remains constrained.

The recognition of the users and the particular context of usage as crucial factors for researching and designing autonomous extension services has been growing. This acknowledgment is justified by the limited number of really efficacious experiences within this field. There is a contention among scholars that the incorporation of user-centered methodologies, such as human-centered, co-creation, or participatory approaches, is imperative for ensuring the sustained efficacy of digital extension services. According to Savolainen [9], the utilization of user-centered approaches can provide developers with guidance in the design and implementation of interventions that align with the specific needs and contextual factors of users. The existing user capacity and the integration of digital and agricultural systems can be considered as promising starting points for the development of a design strategy. Prior to commencing the design process, it is advantageous to acquire a comprehensive understanding of the intricate context where new autonomous extension services must assimilate and align. This can be achieved through the implementation of an ex-ante assessment, which encompasses an evaluation of various factors including the prevailing agricultural information practices employed by the target users, customary modes of communication, and the significance of diverse (digital) media in the dissemination and reception of information.

In order to facilitate the process of making complex and distinctive decisions, we offer the Agricultural Information Systems Development Kit, an innovative framework that integrates data through the utilization of digital technologies, with a focus on system-oriented approaches. The purpose of this framework is to facilitate the development of agriculture that is both multifunctional and diverse. The fundamental requirements upon which the AISDK was constructed are delineated and explicated, having been derived through a process of iterative deliberations with relevant stakeholders and consortium members, as well as a comprehensive examination of extant digital agricultural software.

IV. RESULTS

Iterative process to institute the requirements for the AISDK

The iterative process involves a series of successive iterations that encompass the stages of development, testing, and improvement of an ongoing project. Teams that employ iterative development methodology engage in a project by following a cyclical approach, wherein each cycle encompasses the stages of creation, testing, and revision. An iterative process refers to a methodical approach characterized by repeated cycles of trial and error, aimed at progressively approaching the desired outcome. While iterative procedures play a crucial role in lean techniques and Agile project management, they can be implemented by any team. The objective of the iterative process is to enhance the design, product, or execution of the project until all stakeholders are satisfied with the outcomes.

In order to guarantee the advancement of valuable tools, which effectively addresses the requirements of a user, incorporates systematic novelty, and upholds policy significance, we prioritized the utilization of a participatory approach rooted in the co-production of knowledge. A total of 8 semi-structured workshops and meetings were conducted with shareholders. The AISDK project incorporated two Stakeholder Advisory Boards (StABs) in Bavaria and Brandenburg, Germany, to facilitate regular feedback from stakeholders during the development phase. To demonstrate unique requirements of relevant stakeholders and design a versatile tool applicable in various contexts, the selection of case studies was based on variations in pedoclimatic features and landscape, field arrangements and sizes, as well as local political dynamics and social expectations. The procedure informed the AISDK in terms of users, goals, functionalities, as well as spatiotemporal and thematic scopes. The findings of the discussion also had an impact on the criteria selection for the literature study.

Designing of the AISDK proof of concept and architecture

The AISDK architecture was developed using a design thinking technique, as outlined by Hong, Lee, and Korea Institute of Design Research Society [10]. This involved engaging the group members in designing the general technical and conceptual architecture of the framework, as well as defining the interfaces between its different elements. The objective was to facilitate the advancement of productive interdisciplinary collaboration and establish a robust theoretical and practical foundation. To accomplish this objective, we implemented a system of regular meetings for theme task forces, which encompassed various areas such as database design, management design, decision-making indicators, and procedures. These meetings occurred on a weekly or monthly basis. Additionally, monthly meetings were held across and within the work package of projects.

The AISDK is currently being subjected to testing in two geographically distinct agricultural regions in Germany, namely Bavaria and Brandenburg. The test zone in Bavaria exhibits smaller land parcels and a greater abundance of structural elements compared to Brandenburg's test zone, which is characterized by larger, uniform fields. In this study, we demonstrate the implementation of grassland buffer patches as a case study to illustrate the practical application of this method in the Brandenburg test area. This facilitates the assessment of the validity of the theoretical and practical linkages among the different components of the AISDK. The use case serves as a technical depiction of the practical application of the AISDK by end-users, contingent upon their specific requirements and the implementation of management directives. We are concurrently pursuing multiple experimental endeavors to advance the utilization of AISDK components, while also assessing their applicability and validity.

The study aims to assess the availability and demand of ecosystem services (ESS) and biodiversity potentials in Märkisch-Oderland and Oder-Spree regions using two landscape windows measuring 5 km by 5 km. Additionally, the provision of ESS will be monitored on a case-by-case basis through a range of experimental fields. These fields include the patchCROP experimental field, which focuses on small-scale patch cropping, the Paulinenaue experimental field, which examines grassland systems, and the Löwenberg experimental field, which investigates agroforestry techniques.

Requirements for the AISDK

In a series of consultation and workshops, consortium members and stakeholders engaged in active discussions regarding the fundamental criteria pertaining to the users, goals, and functions of the AISDK, alongside its thematic and spatiotemporal scopes. The significance of prioritizing and recognizing farmers as crucial beneficiaries and users of the tool, including guaranteeing alignment between the tool's vision and the perspectives of key stakeholders such as civil society, farmers, policy officials, and others, was emphasized through iterative dialogues. The AISDK's consortium members and stakeholders reached a consensus on three primary objectives, which subsequently guided the formulation of its fundamental three functionalities. In the initial phase, forthcoming agricultural systems will be administered with a focus on the multifunctionality inherent in diverse agricultural systems.

The second objective pertains to the inclusion of Ecosystem Services and biodiversity as integral components in the decision-making processes of farmers. The AISDK's capability enhancements in the domains of education and communication have garnered significant enthusiasm from stakeholders. In order to achieve its objectives, the AISDK was developed with three fundamental components: (i) the ability to monitor and assess production, biodiversity, and ecosystem service provision; (ii) the provision of decision-making assistance to farmers in relation to ecosystem service provision, sustainability, and biodiversity; and (iii) the enhancement of collaboration and communication channels between farmers and other key stakeholders.

In order to accomplish these objectives, it is imperative for the AISDK to adopt a comprehensive thematic framework that encompasses various dimensions of sustainable agriculture, such as production, environmental considerations, and socio-economic factors. This approach will enable the AISDK to fully exploit the potential offered by digital technology. In order to achieve effectiveness, it is imperative to consider the diverse range of pedoclimatic, economic, policy-related, socio-cultural, and various other factors that influence the decision-making process of farmers regarding land use and management. Furthermore, it is imperative to effectively collect and incorporate datasets related to ecosystem services and biodiversity provision, while also considering the demands of sustainability of various key stakeholders and managers of land. Additionally, it is crucial to conduct comprehensive evaluations to evaluate possible effects of different land-management alternatives on a diverse range of biodiversity outcomes and ecosystem services.

The requirements of the AISDK pertaining to temporal and geographical coverage indicate the necessity of developing solutions that address objectives across different spatial and temporal scales. The consideration of field, sub-field, landscape scales, and farm is essential in the formulation biodiversity supply and demand, and of ecosystem services. The AISDK's site-specific optimization suggestions can assist users in effectively aligning agricultural choices, such as crop variety and management procedures, to mitigate conflicts and trade-offs. Enhancing the effectiveness and ease of collaborative agricultural initiatives spanning farm boundaries or landscapes can be achieved through the consideration of neighboring or non-farm stakeholders' preferences. Finally, it is imperative that the AISDK satisfies the prerequisite of encompassing a wider community perspective, encompassing the consideration of both immediate and long-term effects on national and regional objectives related to sustainability.

Literature review results on digitalized agricultural tools

In the year 2017, a significant milestone was achieved in the field of digital agriculture, commonly referred to as "smart farming" or "e-agriculture." This milestone involved the mechanized cultivation and harvesting of a crop, marking the first instance where the entire process, from sowing to management, was carried out exclusively by automated machines. Digital technologies such as the Internet, mobile gadgets and technologies, artificial intelligence, data analytics, digitally-produced applications and services have a fundamental impact on agriculture and the food chain. The utilization of traceability technologies and digital logistics services presents an opportunity to optimize agri-food supply chains and furnish reliable information to consumers. Additionally, these technologies enable the refinement of inputs and mitigate the requirement for manual labor. Additional illustrations can be observed at different stages within the agri-food value chain, including the mechanization of agricultural equipment, the utilization of satellite data from remote locations, and the deployment of in-situ sensors.

Governments can potentially derive advantages from the utilization of digital technology, as it has the potential to improve the effectiveness and efficiency of existing policies and programs, as well as facilitate the creation of novel initiatives. For example, the cost associated with monitoring multiple agricultural operations is significantly diminished due to the availability of publicly accessible and high-quality satellite imagery. Consequently, governmental entities may possess the capability to enact more intricate policies that offer incentives or penalties to farmers based on the environmental outcomes they deliver. Digital technology enables the digitalization of agricultural management activities and facilitates the designing of new governmental services such as extension and advising programs. Additionally, it is utilized to ensure adherence to environmental regulations.

Lastly, digital technologies have the potential to enhance agricultural and food product trade by establishing connections between private sector suppliers and untapped markets. Additionally, they enable governments to implement novel approaches for monitoring and ensuring standards, while also streamlining border procedures to expedite the movement of perishable goods, which holds significant importance. These technological advancements have the potential to contribute to the development of agricultural and food systems that are more resilient, productive, and sustainable, thereby better meeting consumer demands. There are two primary avenues through which benefits are realized: firstly, by businesses and organizations within the sector (e.g., service providers) employing technology, and secondly, by governments utilizing technology to enact more efficient policies.

The increasing comprehension within the scientific community regarding the advantages of technical and digital applications has led to a corresponding increase in the accessibility of science-based and commercial solutions that leverage advancements in digital technology to improve farm management. Upon conducting an analysis of 42 digital agricultural solutions, it was observed that a significant proportion of these solutions (40 out of 42) placed considerable emphasis on the monitoring of activities. This emphasis on monitoring is typically associated with the objective of optimizing production.

The collected monitoring data is subsequently utilized in tandem with decision-making algorithms to assist farmers in strategic planning and operational design (30/42). A mere 14 out of the total 42 instruments effectively enable and promote interaction among farmers and various other stakeholders. Regarding technology, 8 out of 42 tools are currently exploring the utilization of artificial intelligence for the purpose of agricultural decision support. Additionally, 21 out of 42 tools rely on data obtained through remote sensing, while 22 out of 42 tools integrate data acquired through in situ sensing for monitoring objectives.

After the initial screening process, we proceeded to select 13 tools for further analysis. In this subsequent evaluation, we examined each tool's thematic and spatiotemporal scope, as well as its functions and the digital technologies it employs. Included in the list of agricultural technology platforms are Agricolus, 365FarmNet, Agricon, CropSat, Conservis/ClimateFieldView, FarmersEdge, LandCaRe, FarmNET, NaLamKi, SMAG, Trimble Farmer Pro/Advisor Prime, NEXT Farming, and Topcon Agriculture Platform (TAP).

Spatiotemporal and thematic scopes

The primary emphasis of all tools is on crop production, with certain tools also incorporating an examination of animal production (refer to **Fig 2**). It is worth noting that the depiction of production outcomes and processes holds significance across all tools. More than 50% of the tools consider different factors of the environment such as greenhouse gas emissions, soil health, water quality and quantity, and biodiversity. Despite the favorable environmental impacts associated with precision farming, it is worth noting that the majority of technologies in this field offer users a limited perspective. Several tools effectively depict the economic landscape by incorporating a dedicated section for farm economic analysis. This section encompasses various aspects such as revenue and gross margins, farm stocks, cost summaries and financial planning, across distinct operational cases. Additionally, these tools offer report generation features to further enhance the analysis process. The absence of a clear portrayal of social dynamics, such as collaborative interactions among participants or advancements aligned with the sustainable development goals (SDGs), is evident.

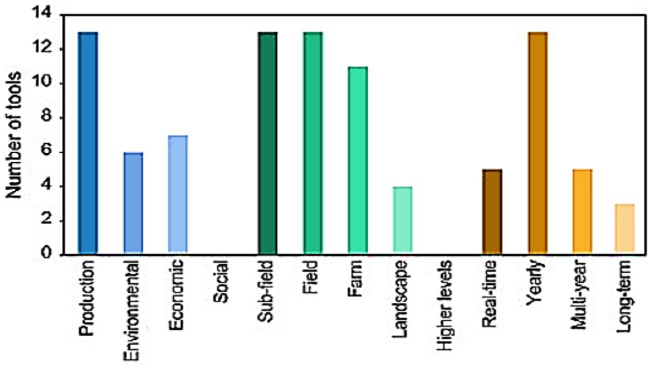

Fig 2. Digital agricultural tools analyzed provide support for both thematic and spatiotemporal scopes.

The spatial and temporal precision of the instruments is indicative of their focus on the aspect of production. The central emphasis of production dynamics lies in annual planning, yet it also encompasses the consideration of sub-field, field, and farm-level impacts as well as long-term preparation. The consideration of environmental consequences typically focuses on output at the sub-field to farm level, with limited examination of the broader landscape-level implications. The instruments utilized in agricultural contexts may adopt either a short- or long-term perspective on economic processes, depending on their specific purpose.

Functions and technologies

The enhancement of yields and production levels is a central objective across various tools, as evidenced by our results regarding the significance of biodiversity, surveillance productivity, and ecosystem service provision (refer to **Fig 3** (a) for detailed information on the functions of the tools). In order to mitigate negative impacts on agricultural productivity and optimize resource utilization, it is imperative for farmers to actively monitor the well-being of plants and proactively identify indicators of stressors such as crop diseases and water scarcity. Digital monitoring is facilitated through the utilization of advanced technological resources such as satellites, unmanned aerial vehicles (UAVs), on-farm weather stations, vehicles and robots equipped with N sensors, and in-situ soil sensors (refer to **Fig 3** (b); for a comprehensive overview of the employed technologies). The aforementioned digital technologies often exhibit a high degree of compatibility and synergy. Sensing technologies are utilized to collect data, which is subsequently subjected to analysis through the application of models and artificial intelligence (AI). In order to enhance the monitoring procedures, manual collection of soil samples is conducted. Limited initiatives currently exist that utilize monitoring data as input for carbon offsetting objectives that are recognized and rewarded by civil society.

Similarly, there is a lack of utilization of such data to enhance biodiversity conservation, for instance, through the identification of fawns using unmanned aerial vehicles (UAVs). This assertion holds particular validity when contemplating the surveillance of ESS and biodiversity. Certain applications emphasize their capacity to track agricultural operations and gather organization data for the purpose of generating reports. This enables farmers to access subsidies and fulfill the criteria for organic or GMO-free certification. However, it is evident that the focus of technologies is primarily on tracking production and generating administrative documentations for standard and regulatory compliance purposes, rather than on monitoring the supply of ecosystem services and biodiversity.

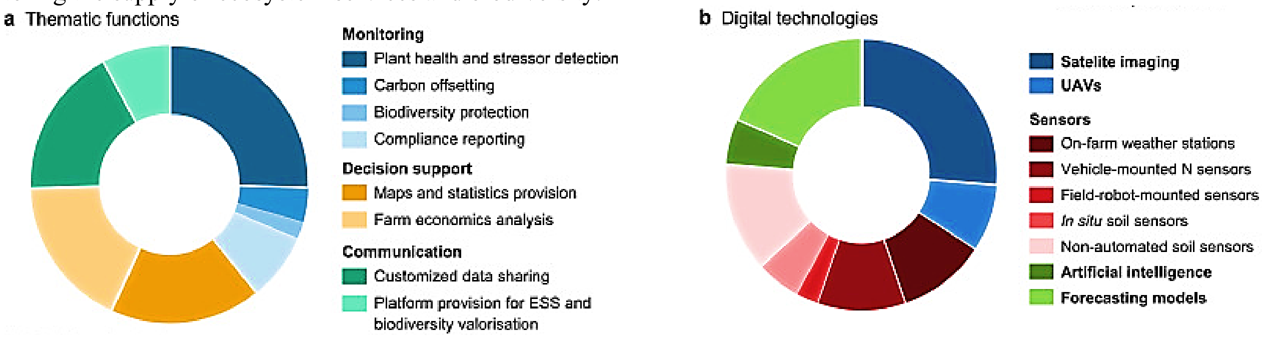

Fig 3. Digital agricultural tools under investigation, categorized by the quantity of functions (a) and digital technologies (b) they are capable of supporting. A single tool has the potential to belong to multiple categories due to its integration of digital technology, enabling it to carry out diverse functions.

Monitoring data is utilized to facilitate on-farm decision making in the planning and management of operations. This includes the implementation of tools that enhance seeding and harvesting processes, as well as the proposal of site-specific and accurate pesticide and fertilizer applications. These examples highlight the practical applications of monitoring data in supporting efficient on-farm decision making. Furthermore, it is common for individuals in this field to collect and evaluate agricultural economic data in order to document, perform accounting tasks, or investigate the potential economic consequences of implementing a proposed alteration in management practices. This is frequently achieved through the compilation of cost summaries pertaining to various operational scenarios, including profit contribution calculation, cost-performance estimates, and other cost summaries types. In order to maximize profitability while concurrently acknowledging the importance of ecosystem service sustainability and biodiversity preservation, it is imperative that tools are developed to provide guidance on a range of land use and investment alternatives. Hence, the decision-making process of farmers does not promptly manifest the integration of biodiversity and ESS. The primary focus of incorporating environmental metrics for biodiversity and ESS is typically on yield, resulting in the optimization of production as a secondary outcome, if considered at all.

When examining the three roles, it becomes evident that the role focused on facilitating collaboration and communication among farmers and other social elements to meet community expectations regarding biodiversity and ecosystem services (ESS) is notably underrepresented in the majority of instruments. However, it is worth noting that some initial promising initiatives have been acknowledged. Various tools exist that offer a platform for the recognition of environmentally or climate-friendly farming practices. These tools include the option to purchase carbon offset credits and provide monetary incentives for the provision of ecosystem services. Additionally, there are tools that facilitate communications and foster collaborations between farmers and other stakeholders. For instance, they encourage partnerships between farmers and agribusinesses. The regulation of on-farm application of manure as well as other fertilisers is becoming more stringent in livestock-intensive parts of Europe, primarily to safeguard aquatic habitats.

In Denmark, there exist communities of specialized farms that have established self-governing manure partnerships aimed at effectively managing the manure resource on a landscape scale, while adhering to environmental standards. This promotes the essential equilibrium between the generation of manure and the areas dedicated to agricultural production in intensive livestock farming. The issue of decoupling crop and animal systems as a result of specialization poses a challenge within the context of organic farming. This phenomenon has resulted in a scarcity of manure fertilizers on the majority of farms, while certain farms experience an excess of such fertilizers. One potential strategy for addressing this issue involves the establishment of collaborative partnerships among individual farms. In order for farmers, advisers, and policymakers to perceive collaboration as a feasible future approach, it is imperative to obtain additional insights pertaining to the extent and efficacy of existing partnerships.

A comprehensive analysis was conducted by Köninger, Lugato, Panagos, Kochupillai, Orgiazzi, and Briones [11] on nationwide registration data pertaining to farmers' manure management systems, with the aim of obtaining a thorough understanding of the manure network. In order to gain a deeper comprehension of the characteristics and roles of collaborative arrangements, both in a general context and specifically among organic farmers, a survey was conducted. The survey focused on a sample size of 1,500 individuals involved in the exportation of manure, and was based on an analysis of registry data. The primary objective of this survey was to identify the key factors that contribute to the success of partnerships within this domain.

The statutory environmental restrictions in Denmark have been in place for more than ten years. Consequently, a significant number of farmers, accounting for 50% of all farms, have formed alliances to identify and implement efficient resolutions. Strategic alliances with external entities, such as manure partnerships and other collaborative arrangements observed in this project, can be perceived as a means to align farm management practices with statutory obligations, capitalize on regional circumstances, and enhance the viability of the agricultural enterprise. A total of 644 individuals were included in the study, and they underwent multivariate evaluation, certainly cluster analysis and multiple correspondence evaluation. The purpose of this analysis was to investigate the characteristics of the partnerships formed, the patterns they exhibited, and the duration of the relationships that formed among the participants. A significant proportion of exporters typically possess a pre-existing affiliation with their business counterpart, which may manifest through personal or social associations. The dynamics of partnerships, including the allocation of tasks related to the transportation and distribution of manure, the frequency of communication, the duration of collaborative efforts, and the geographical extent of travel, are significantly shaped by the diverse social relationships existing among the involved parties.

The findings of this study contribute to the existing body of knowledge derived from spatial-economic models, which primarily emphasize economic factors in the resource assignment decision making process. The examination of farm registration data reveals that there is a significant interconnection among organic farms in Denmark in terms of manure export and import. This network primarily encompasses farms located in regions with a high concentration of livestock-intensive activities. A comparative analysis was conducted on a total of 95 organic dairy-arable partnerships in Northern and Western Jutland, in addition to 144 conventional dairy-arable partnerships in the same region [12]. The objective of this study was to gain a deeper understanding of the potential effects of organic farming requirements on the characteristics and operations of these partnerships. The requirement for organically certified manure in organic arable farming has a substantial influence on the characteristics and functioning of organic partnerships.

A significant finding of the study was that organic dairy-arable couples exhibited robust social connections, irrespective of their physical separation. Limited research has been conducted on the perspectives of livestock producers regarding coordinated agreements with recipient farms and the factors contributing to successful cooperation, despite the potential for enhanced efficiency in the utilization of manure. A survey was conducted among a total of 644 farmers to ascertain their perspectives on the factors they considered to be of utmost importance, as well as those they considered to be of least importance, when selecting a manure-receiving business partner. Additionally, the survey aimed to identify the factors that farmers believed were crucial in maintaining a healthy business relationship with their chosen partner. The assessment of farmers' opinions was conducted through the process of ranking a comprehensive list of 18 statements. The findings indicated that farmers perceived the arrangement as successful when they had confidence in their partners' trustworthiness, perceived a promising future for the relationship, and had convenient access to their partners both in physical proximity and through online communication channels. The significance of effective and timely communication, along with a certain level of flexibility in the arrangement, is widely acknowledged.

In order to conduct a more comprehensive analysis of the variables influencing the perceived effectiveness of collaborative efforts among farmers, a series of stepwise multiple regressions were employed. These regressions aimed to explore the impact of various factors, including age, production type, location, and prior experience with manure arrangement. The relevance of past partnership experiences in the search for new partners is contingent upon factors such as the age of the farmer and the scale and nature of their business operations. The perspectives of farmers regarding the productive collaboration were significantly shaped by the geographical location of their farms, particularly whether they were situated in regions predominantly focused on arable farming or livestock rearing. Given the volatile nature of global market conditions and the increasingly stringent regulatory environment, it is imperative for farmers to establish collaborative partnerships that can facilitate adaptation and enhance flexibility. There remains a necessity for employing a qualitative methodology that seeks to inquire about the underlying reasons behind farmers' engagement in manure collaboration, thereby facilitating a more comprehensive comprehension of this phenomenon. The findings derived from this research endeavor would enhance the existing understanding, thereby increasing its utility for various stakeholders such as farmers, local agricultural advisors, and policymakers.

V. LIMITATIONS AND FUTURE OF THE AISDK

Limitations

The continuous development of digital agricultural tools is a manifestation of the latest technological advancements and user preferences. The utilization of digital agricultural technologies is contributing to the enhancement of food systems' adaptability and resilience against disruptions. Amidst the epidemic, farmers have exhibited a notable inclination towards three distinct categories of digital tools, namely digital advising, agricultural digital banking services, and Agri e-commerce solutions. A number of compelling digital tools are currently in the initial stages of development, focusing on specific themes or spatiotemporal scopes, with the potential or intention to broaden their scope in the future. This implies that the conclusions drawn from this review may become outdated quickly. Furthermore, it is worth noting that the descriptions of the evaluated tools may exhibit a deficiency in providing comprehensive information regarding certain specific features, such as the various types of models and algorithms employed, as well as the dynamics and scales of sustainability. This lack of explicit information is occasionally observed in the reviewed documentation.

The AISDK, along with its distinctive characteristics, forms the foundation for the criteria used to determine which tools will be further examined. This restricts the range of tools present for detailed analsis on only those that strive to incorporate multiple functions and digital technologies. The rigid selection procedure resulted in the removal of tools that had similar functionality within specific domains and thematic scopes (such as cattle husbandry or horticulture), as well as tools that focused solely on a single function. While our methodology may restrict the inclusion of certain features, it is evident that current tools are inadequate in addressing essential ecosystem services (ESS) and biodiversity, promoting effective communication and collaboration, and integrating multiple spatial systems.

Future Projections

If farmers were granted access to the Agricultural Information Systems Development Kit (AISDK), they would be capable of fulfilling society's demand for ecosystem services and biodiversity. The successful implementation of these approaches on a large scale necessitates significant support and endorsement from both individual stakeholders at the farm level and key players in the industry and policy sectors. The principles and tools outlined in this study possess significant potential in facilitating sustainable agricultural transformation and promoting the adoption of site-specific and adaptable agro-ecological management strategies. The progress made in agricultural and agri-food systems necessitates the implementation of structural modifications. These adjustments are required to enable the establishment of novel means of communication between producers and consumers, as well as to enhance the design of value chains. Additionally, they are crucial for addressing concerns related to data privacy and storage. An essential element of this transition involves the utilization of digitalization as a means to enable the creation of inventive policy tools, which provide targeted aid for sustainability and increase the advantages of agricultural practices.

In order for the concept of multifunctional and diverse agriculture to gain widespread acceptance, it is imperative to establish feasible economic alternatives to existing agriculture frameworks. Policy instruments such as the eco-schemes under the EU Common Agricultural Policy [13], as well as the promotion of private stakeholders between individuals, companies and farmers through online marketplaces like www.agora-natura.de, have the potential to address the absence of economic incentives that currently hinder the ecosytem service provision and biodiversity in agricultural practices. The AISDK possesses the capability to assess the effects of current and potential biodiversity and ESS payment systems on decisions regarding land utilization and management, with the aim of optimizing biodiversity and ESS provision. By providing farmers with information on the most economically efficient strategies to fulfill biodiversity and ecosystem services (ESS) requirements, and enabling them to objectively assess the impacts of different schemes, this approach holds promise in mitigating the prevailing uncertainty surrounding the actual value of these two aspects. Therefore, it is observed that the utilization of public and market-oriented economic mechanisms to enhance the value of ecosystem services and biodiversity is increasing. In this context, the AISDK, whether employed as a system or as a provider of model components, can offer a viable approach to measure the quantity of services required and provided within different public or private frameworks, as well as facilitate the connection between service providers and consumers.

The AISDK should be examined for its potential to enhance extension service and biodiversity provisions in agriculture among various users and within a policy framework, in addition to its application in farming. Farm advisors play a crucial role in assisting farmers in capitalizing on synergistic opportunities and reducing expenses, not only within the immediate farm setting but also in the context of broader landscape and regional planning. This would be advantageous from a pragmatic perspective as it would facilitate farmers' integration into the AISDK system and enhance their understanding of its implications for agricultural management, while simultaneously reducing potential obstacles related to technology, finance, administration, and knowledge. The AISDK offers a novel framework that leverages digital agriculture to enhance traditional farm management practices and transform the utilization and integration of diverse information streams pertaining to agricultural landscapes. The AISDK presents a versatile framework architecture for the management of intricate data connections, facilitating seamless scalability of the encompassed datasets and land management alternatives in accordance with the objectives of end-users, their associated information requirements, and the availability of data.

VI. CONCLUSIONS

The advancement of digital technology has made significant progress over the past decade, resulting in a diverse range of solutions that cater to a broad spectrum of requirements. The examination of existing resources reveals ongoing challenges in the creation and execution of digital decision support systems (DSS) for agricultural models, certianly based on biodiversity and ecological service integration, enhancing collaboration and communication among farmers and relevant stakeholders, and connecting various spatial and temporal scales and broader sustainability dimensions. The AISDK was developed with a clearly defined requirement framework, which was formulated through collaborative and iterative processes, incorporating insights from prior research and accumulated knowledge. The Agricultural Information Systems Development Kit (AISDK) utilizes digital technologies to develop a Decision Support System (DSS) that facilitates the integration of Environmental and Social Sustainability (ESS), biodiversity, and sustainability considerations into the decision-making processes of farmers. This DSS assists farmers in adopting site-specific, small-scale, multifunctional, and diversified agricultural practices, which are aligned with their own defined pathways. This study examines the diverse factors that influence agricultural management design and land use, and agronomic and natural components, policy and economic factors, and socio-cultural contexts and preferences. It compiles and analyzes a comprehensive set of dynamic and static data from manifold sources, which are then presented to the user vital an interlinked spatiotemporary explicit framework. The AISDK aims to engage key stakeholders in the long run by emphasizing the significance of its outputs at both farm-level and the sub-field scales. Additionally, it seeks to establish a learning model, which enhances inclusive stakeholder involvement on sustability goals.

Data Availability
No data was used to support this study.

Conflicts of Interests
The author(s) declare(s) that they have no conflicts of interest.

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