Fostering Trustworthiness Evolution of Smart Solutions in Agrifood: Challenges and Barriers

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***Abstract*—The ongoing integration of innovative smart solutions in the agrifood sector significantly benefits productivity, sustainability, and resilience, but also raises concerns about trustworthiness. This paper provides an overview of the main challenges and barriers to trustworthiness and current strategies and cybersecurity measures to bolster trustworthiness. The paper also discusses a possible conceptual solution for the sustainable evolution of smart solutions in the agrifood sector and provides a preliminary implementation based on a digital innovation hub.**

***Index Terms*—Trustworthiness, Innovative Solutions, Agrifood, Challenges and Barriers**

I. Introduction

With the widespread adoption of new technologies such as the Internet of Things (IoT), the industry 4.0 and 5.0 [1], the digital revolution and the evolving of innovative solutions [2] trustworthiness is becoming a baseline term.

Establishing trust between individuals, organizations, and systems hinges on a few essential aspects. Reliability, credibility, and integrity are crucial elements in building trust. It entails following through on commitments, maintaining confidentiality, and adhering to ethical standards. Additionally, being transparent, dependable, and confident in your interactions with others is crucial. Prioritizing trustworthiness helps create a strong foundation for cooperation and collaboration.

In the agrifood sector, technologies also profoundly impact and radically change the business and production processes. In this situation, on the one hand, the integration of technological advancements, such as artificial intelligence (AI) [3], blockchain [4], smart agent, and sensor networks [5] are revolutionizing agricultural practices, enhancing food safety, improving supply chain efficiency, and promoting sustainable practices. On the one hand, these technologies' successful adoption and evolution are raising concerns about security, privacy, reliability, transparency, and ethical considerations among stakeholders, including farmers, consumers, government bodies, technology developers, and industry players.

Establishing and upholding stakeholder trust in innovative agrifood technology is crucial to promoting acceptance and practical implementation and preventing resistance and scepticism that could hinder progress and innovation in the sector.

Therefore, this paper examines the challenges and obstacles that hinder the progress and improvement of trustworthiness in innovative smart solutions in the agrifood sector. In addition to a standard literature overview, 30 experts in community agrifood, cybersecurity, human science, IoT, Smart environment, and trust were interviewed to gather information. The information and results provided a theoretical basis for implementing trustworthiness strategies, creating a collaborative environment for the sustainable evolution of innovative smart solutions, and fostering trustworthy collaborations between stakeholders.

Considering the vast research area, the state-of-the-art analysis and expert interviews have been targeted to find replies to the following research questions:

RQ1 What is the perception of trustworthiness in the agrifood domain?

RQ2 Which are innovative smart solutions currently impacting trustworthiness?

RQ3 What are the challenges and barriers to adopting smart, innovative solutions in the agrifood sector?

Additionally, to propose future research guidelines for addressing the challenges and barriers evidenced by these research questions, the paper also presents the building block of a conceptual solution and the ongoing work for their implementation based on collaborative governance models, transparent communication channels, robust cybersecurity measures, and capacity-building initiatives.

Road-map: This paper is structured as follows: in the next Section II, trustworthiness perception is defined while in Section III, the relation with innovative smart solution and trustworthiness is analyzed. Section IV discusses the collected challenges and barriers. Section V describes the building block of a conceptual possible solution, and the ongoing work for their implementation is presented in Section VI. Conclusions and future work ideas are reported in Section VII.

II. Trustworthiness perception

Considering the first research question: *RQ1: What is the perception of trustworthiness in the agrifood domain?*, data collected during the state-of-the-art analysis and expert interviews evidenced that usually, in the agrifood sector, perception of trust mainly involves interpersonal trust among value chain actors (i.e.farmers, buyers, sellers, retailers, and intermediaries, suppliers, and retailers).

Indeed, trustworthiness is often associated with the reliability, credibility, and integrity of the agricultural and food systems and includes consumers' level of trust in the safety, quality, sustainability, and ethical practices associated with agricultural products and the food supply chain [6]. Thus, the perception of trustworthiness in agrifood mainly includes:

- *Safety and Quality Assurance:*, i.e., ensuring products are safe for consumption and compliant with quality standards is essential for customer satisfaction and regulatory compliance.
- *Transparency and Traceability:* i.e., information about production methods (practices, origin, and authenticity), ingredient sourcing, and environmental impacts are reported and traceable.
- *Sustainability and Regulatory Compliance:* i.e., the production process minimizes environmental impact and complies with industry standards about safety, quality, and ethics[1] [2].
- *Improvement and Optimization:* i.e. ensuring quality control processes and regular audits and reviews are put in place to increase competitiveness and long-term success.

In refining the reply to the RQ1, the data collected by experts in domains closer to technical and engineering sectors suggested that trustworthiness becomes more related to data management, such as data sharing, storage, and certification. [7].

Indeed, in recent years, with the advent of digital transformation, trustworthiness perception has started to include other topics closer to the standard definition. Thus, the agrifood domain and industry have begun to realize the significance of sharing and processing trustworthy information. It includes managing information systems and processes, understanding the application context, and the relationship between data and knowledge.

The sector has also started considering the certification, standardization, and quality of adopted digital tools and technologies. Trustworthiness in their interaction, integration, and role in the supply chain is also being considered.

III. Innovative smart solutions v.s. trustworthiness

Considering the second research question: *RQ2: Which are innovative smart solutions currently impacting trustworthiness?*, data collected during the state-of-the-art analysis and expert interviews evidenced that the contexts in which synergy between innovative smart solutions and trustworthiness concepts are mainly in relation are:

- *Blockchain* because this technology can enhance trust between stakeholders, increase the traceability and transparency [8].
- *Mobile and e-services* because fundamental for leveraging communication and accessing agricultural-related information [9].
- *Unmanned aerial vehicles (UAVs)* because UAVs can improve crop care, yield monitoring, estimation of business and monitoring processes [10].
- *Smart sensors and Internet of Things (IoT)* because these technologies help manage and monitor environmental conditions (such as crop, soil, or weather), food traceability, especially for organic farmers, supporting data transfer and collection and (cloud) storage, implementing notifications and alerts [11].
- *Artificial intelligence (AI) and robotics* because they can improve human and industrial workflow capabilities in all the production processes, especially in the case of fully autonomous procedures and operations (such as irrigation automation [12]).
- *Mobile and web applications* because they allow remote management tracking and updates. They also support data collection and use all emerging technologies and applications [13].

As a final remark in the replying of RQ2, the data analysis evidences that even if society, environment, and context are changing, fostering trustworthiness in innovative smart solutions in the agrifood sector still has many challenges and barriers to be overcome.

IV. Challenges and Barriers

Considering the third research question (RQ3: what are the challenges and barriers to adopting smart, innovative solutions in the agrifood sector?), the data collected by experts in domains closer to technical and engineering industries suggested many exciting suggestions. In particular, five main challenges and barriers to the widespread adoption of smart, innovative solutions and technologies in the agrifood sector from a trustworthiness perspective be summarized in the following areas:

CH1: *Data Security and privacy.* As in other Internet of Things (IoT) domains, ensuring the best data security and privacy practices in the agri-food sector is an ongoing challenge. The growing use of smart solutions has led to the generation of a large volume of data, much of which is personal or sensitive and, therefore, requires protection from unauthorized access or cyber-attacks. One potential solution could be incorporating cybersecurity measures into the design process and establishing effective testing and monitoring procedures [14].

CH2: *Integration and Interoperability.* The agrifood industry is getting more complex daily, and to achieve a common goal, it is crucial to integrate various smart technologies such as blockchain, AI, sensors, and devices. However, implementing and troubleshooting these solutions can be challenging, which may raise concerns about their reliability, accuracy, and vulnerability to cyber threats. Moreover, the lack of global governance, formalized requirements, and compatibility among different smart technologies and platforms can significantly compromise their overall performance and quality. Trust issues can be experienced in data management, communication protocols, and application and system interoperability. It can

[1](https://www.iso.org/standard/62085.html)

[2]https://www.iso.org/standard/27001

compromise stakeholder resources' access, collaboration, and data management, decreasing global trust perception. Therefore, it is essential to establish standard guidelines and specific solutions to address integration, compatibility, and interoperability issues to improve the scalability and effectiveness of smart technologies. [15].

CH3: *Knowledge sharing and inclusiveness.* Lack of knowledge about innovative smart solutions and their complex technologies can create uncertainty in their adoption and prevent widespread usage despite their effectiveness. A solution to these challenges is to provide supporting learning systems, user-friendly guidelines, and adequate training and education programs. It is essential for small-scale farmers or those with limited technical expertise. In addition, knowledge sharing can effectively solve disparities in access to technology and digital literacy, improve inclusiveness, and overcome scepticism about smart solutions. Indeed, these factors could influence the perception of trustworthiness and the ability to participate in and benefit from technological advancements [16].

CH4: *Equipment and Facilities.* The implementation of smart solutions often requires a significant upfront investment in equipment, software, and other facilities, as well as ongoing maintenance costs. It can be a major obstacle for small businesses or those in rural areas. Furthermore, unreliable internet connectivity, lack of electricity, and limited access to technology can prevent realizing the benefits of technological advancements. Therefore, developing sustainable and low-cost solutions to improve digitization in these contexts is crucial, enhancing trust and encouraging further progress.n [17].

CH5: *Innovation Ecosystem and market.* A significant challenge remains to transfer the concept of an innovation ecosystem to the agrifood domain for fostering evolution and innovation among actors, activities, artifacts, institutions, and relations. However, having a strong and integrated innovation ecosystem can be the key to developing and launching solutions quickly that efficiently solve real-world problems. It provides access to resources, increases the flow of information, leverages knowledge, and improves global trustworthiness. Furthermore, it can have a role in solving the fragmented market structure, with numerous stakeholders involved in production, distribution, and retail. It can leverage coordination and cooperation between stakeholders, promote the adoption of smart solutions, and improve knowledge and data sharing despite competing interests and incentives. Finally, the innovation ecosystem can help in the risk evaluation and management of smart technologies. It can reduce uncertain returns on investment and market, build confidence, and demonstrate tangible benefits through pilot projects and success stories [18].

As highlighted by this analysis, the final remark in replying to *RQ3* is that overcoming the challenges and barriers faced by the agrifood sector requires a collaborative effort from policymakers, technology providers, agricultural organizations, and other stakeholders. Creating an environment that supports such initiatives is essential to enable innovation, investment, and collaboration. It can be achieved through targeted incentives, capacity-building programs, regulatory reforms, and public-private partnerships that aim to remove obstacles and unlock the full potential of smart solutions in agriculture.

V. CONCEPTUAL SOLUTION

Based on the analysis conducted in the previous sections, a conceptual proposal has been developed to address the challenges described. As shown in Figure 1, the proposed solution focuses on three layers and four building blocks. It aims to provide a social and knowledge-sharing infrastructure that enables users to engage in a collaborative and comprehensive learning and assessment experience. Going into details, the building blocks of the proposed solution are four-folds:

- **Trust Assurance Business Model**. This block focuses on the challenges CH1, CH2, CH3, and CH4 described in Section IV and targets the development of a business model to manage and control digital identities, including stakeholders, resources, and their relationships [19]. The model must establish rules and safeguards for developing intelligent digital assets. It should facilitate digital asset collection and transmission while ensuring traceability. The model should also include maintenance procedures for the lifetime of the digital asset and address ethical concerns related to adopting new technologies.
- **Network collaboration and governance framework**. This block focuses on the challenges CH1 and CH2 described in Section IV and targets conceptualizing the stakeholder's network collaborations, resource interactions, and access policies. This is fundamental for defining the information flow, investment, business, portfolio plans, knowledge infrastructure, and resources to support and improve innovation efficiently. Networking collaboration also promotes the innovation ecosystem and lets entrepreneurs and innovators share experiences among themselves and support one another. Additionally, the governance framework will strengthen the cooperation of the stakeholders of the innovation ecosystems to boost and support innovation and gender equality in their area.
- **Digital Innovation**. This block is the middle layer of the conceptual proposal and focuses on the challenges CH1, CH3, and CH5 described in Section IV. It promotes digital innovation to improve cooperation between the different stakeholders, support innovation, and leverage the socioeconomic development of the communities. As described in Europe's Digital Decade [3] digital innovation is the effective means for improving learning, entertaining, working, exploring, and fulfilling ambitions. It also leverages freedoms and rights, overcoming physical communities, geographical locations, and social positions. Knowledge and digital technologies can improve business decisions, stakeholder interaction, connectivity, public services, and administrative procedures.
- **Technological and architectural support**. This block is the bottom layer of the conceptual proposal and

[3]https://digital-strategy.ec.europa.eu/en/policies/europes-digital-decade

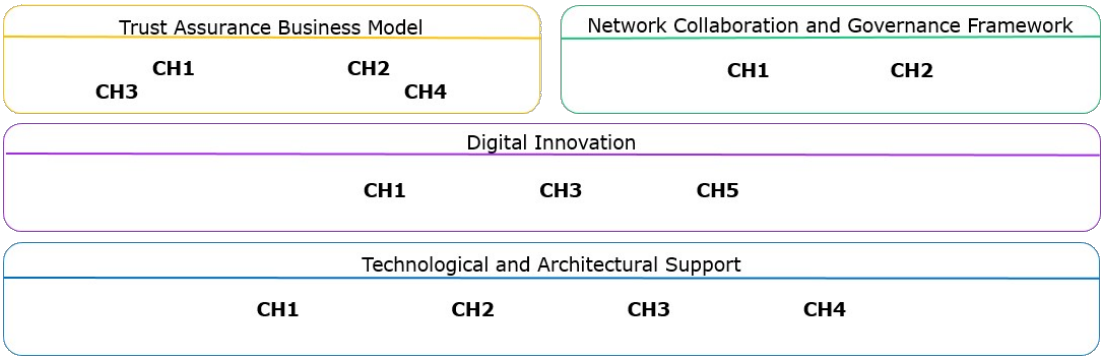

Fig. 1. Building Blocks Solution Layers v.s Challenges

focuses on the challenges CH1, CH2, CH3, and CH4 described in Section IV. The definition of technological and architectural support is fundamental for the correct and efficient management and integration of the smart, innovative solution and for assuring trustworthiness in the supporting tools and features. It also empathizes with and improves stakeholder cooperation and promotes adopting open-source solutions, reducing overall costs and efforts. The design of the architectural support will make the by-design trustable integration of existing solutions useful for creating:

- Thematic forums and collaborative space.
- Integration of existing learning systems and databases.
- Specification of recommendations, data, and information according to users' needs.

VI. Moving into a Digital Innovation Hub

The realization of the previously mentioned building blocks is based on a customized Digital Innovation Hub (DIH) and is currently under development. Usually, a Digital Innovation Hub (DIH) is described as a collaborative platform supporting digital innovation and transformation within a specific sector or community. These hubs typically provide various services, resources, and expertise to help businesses, startups, researchers, and other stakeholders leverage digital technologies effectively [20].

DIH usually includes facilities for interacting with experts in different areas, accessing digital infrastructure (including hardware, software, and platforms), networking among stakeholders, and accessing training programs and funding opportunities. They are essential in driving digital transformation, fostering innovation, and enhancing competitiveness in various industries and regions.

Currently, there are several examples of DIH in the agrifood domain, such as SMARTAGRIHUBS (SAH) [4], which is a multi-stakeholder approach and dedicated agricultural innovation ecosystem, AgriFood DIH (ITC Cluster) [5] focused on digital transformation services to farmers, farmer associations, food producers, the food supply chain actors and solution providers to improve the food supply chain or HIBA- HUB IBERIA AGROTECH, [6] providing multiregional ecosystem devoted to the agrifood sector including training on digital transformation, entrepreneurship, and open innovation programs.

However, despite their adoption and proven usefulness, none of the currently developed DIHs specifically focus on leveraging innovative smart solutions' trustworthiness evolution in the agrifood sector. It motivates the selection and the ongoing work in realizing a new Trustworthiness-based Digital Innovation Hub T_DIH.

Therefore, T_DIH main objective is to provide a social, collaborative, and knowledge-sharing infrastructure that enables users to have a holistic, learning, cooperative, and assessment experience. The T_DIH is being developed to support and advance the existing open source and distributed solutions by providing features for:

- Realizing thematic forums for sharing ideas and knowledge collaboratively.
- Integrating existing learning systems or managing learning content.
- Creating and providing a common database.
- Suggesting documents, data, and customizable knowledge according to the specific needs, business, and stakeholder profile.
- Browsing, collecting, and updating the documentation.
- Providing a collaborative workspace for improving and evolving knowledge, integrating tools and solutions.
- Creating new content and customized learning patterns according to user profiles.
- Providing recommendations, data, and information that can evolve according to emerging user needs and constraints.
- Allowing collection of user's requirements and feedback and assessing the results.

T-DIH is based on the building blocks described in the previous section and provides a by-design trustworthiness solution. In particular, the realization of the *Trust Assurance*

[4]https://www.smartagrihubs.eu/

[5]https://itc-cluster.com/dih-agrifood/

[6]https://hubiberiaagrotech.eu/

business model building block presented in Section V includes the definition of the procedural steps of an iterative, shift-left development process [21] that consist of the following activities:

- Identification of the architectural functional and non-functional properties.
- Definition of the business processes for including the related information and data.
- Definition of the users' profiles, goals and usage patterns.
- Identification of the validation strategies for assessing the architectural, functional, and non-functional properties.

In line with the *Network collaboration and governance framework* building block presented in Section V, the purpose of T_DIH will be to develop and disseminate a governance framework model that helps agri-food stakeholders to implement mechanisms to support trustworthy innovations. The provided feature will include procedures for:

- Conducting the assessment.
- Identifying gaps.
- Selecting possible solutions or directions.

By strengthening the cooperation between innovation stakeholders at the local level, T_DIH will improve service delivery, share and disseminate knowledge and best practices, improve stakeholder skills and opportunities, and foster networking activities among innovators. T_DIH will directly contribute to enhancing innovation in several areas, promote innovation programs in the different pilot sectors, and support the implementation of innovation infrastructure such as coworking space.

Considering the *Digital Innovation* building block presented in Section V, to accelerate the digitalization of the agri-food sector, internet infrastructure should be viewed as a baseline service, as digital technologies require fast, affordable, and reliable Internet access that can only be provided by broadband. It means realizing:

- Standardized governance rules.
- Best practices and technological supports.
- Overcoming the lack of stakeholders' experience in the ICT domain and the difficulties in adopting new approaches and innovations.

Therefore, in targeting digital innovation, support for education, training, and knowledge sharing will be pivotal components for filling technological gaps and transferring and improving the proliferation of innovation and cultural digitalization in the agrifoods sector. Training activities will also enhance trustworthiness and data protection and increase the ICT maturity level, cooperation, and sharing, as well as the possibility of creating compelling and proficient new businesses and new technologies.

Finally, Considering the *Technological and architectural support* building block presented in Section V, T_DIH will promote using open-source solutions to significantly reduce costs and efforts as integrating open-source-specific tools and solutions will counterbalance the difficulties of affording and sustaining technological support for long-term periods.

Compared with existing technological Innovation, T_DIH realization will overcome the following issues:

- Being open source.
- Providing cost reduction.
- Solving low integrability with open-source-specific tools and solutions.
- Solving difficulty in being adopted and managed.
- Providing sustainability for a long-term period.

A. Development process

As shown in Figure 2, in its realization, T_DIH relies on an iterative, shif-left development process to realize and assess by using trustworthy solutions. In its realization, a fundamental principle is to adapt and integrate existing open-source solutions to guarantee the development of a low-cost, integrated platform able to emulate and possibly realize the primary services and features provided by the existing non-free open innovation platforms.

In particular, the following existing open source solutions are currently under evaluation: Content Management Systems (CMS) (like Joomla [7], Learning Management Systems (LMS) (like Canvas [8] and the advanced digital enterprise platform (like X-wiki [9], DokuWiki [10], MediaWiki [11]).

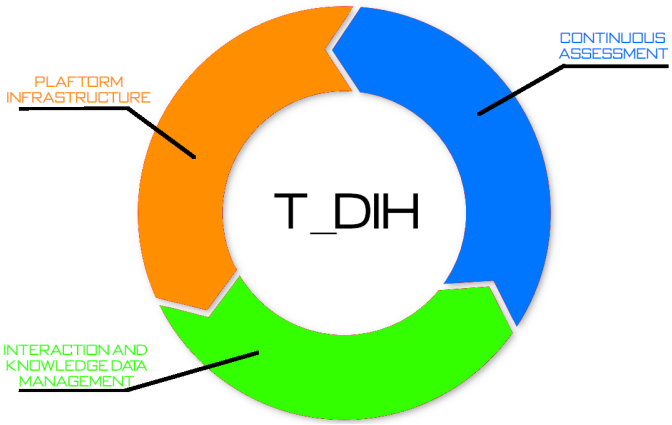

Fig. 2. T-DIH evolutional process

In detail, the development process of T_DIH (see Figure 2) includes the following steps:

- *Platform Infrastructure:* development of a high-level architecture for the T_DIH platform that integrates the tools and features for supporting and advancing the existing open source and distributed solutions. T_DIH provides features for realizing thematic forums and collaborative space, integrating existing learning systems and a shared database, and providing recommendations, data, and information according to stakeholders' needs. In particular, T_DIH exploits semantic web technologies for

[7]https://www.joomla.org/
[8]https://www.capterra.it/software/127214/canvas
[9]https://www.xwiki.org/xwiki/bin/view/Main/WebHome
[10]https://www.dokuwiki.org/dokuwiki
[11]https://www.mediawiki.org/wiki/MediaWiki/it

managing and organizing knowledge and data and relies on the selected open-source Content Management System (CMS). A Shift-left process is used as a reference development model for implementing T_DIH infrastructure incrementally.

- *Interaction and knowledge data management:* T_DIH realization includes the definition of the user's Interaction and the implementation of the data management. Thus, T_DIH provides facilities for supporting users in training and knowledge sharing, mitigating the language and knowledge differences, and managing by-design security and privacy attributes of the stakeholders, data, and shared knowledge. Therefore, the infrastructure will enable users to collaborate and share information and experience in a secure and privacy-preserving way.
- *Continuous assessment:* To improve the trustworthiness, T_DIH includes facilities for continuously assessing innovative smart solutions and collecting feedback and results. The evaluation targets implementing functionalities according to the stakeholders' requirements and expectations.

VII. Conclusions

The paper addressed the critical challenges and barriers hindering the evolution of trustworthy, innovative, smart solutions in agrifood. Through a comprehensive analysis and expert interviews, the paper highlighted the significance of trustworthiness perception in agrifood, focusing on safety, quality assurance, transparency, traceability, sustainability, and regulatory compliance. It also analysed the current impact of various innovative smart solutions, such as blockchain, mobile services, UAVs, IoT, AI, and web applications, on trustworthiness enhancement.

Moreover, the paper listed vital challenges and barriers, including data security and privacy, integration and interoperability, knowledge sharing and inclusiveness, equipment and facilities, and innovation ecosystem and market. Focusing on the necessity for collaborative efforts to overcome the mentioned obstacles, the paper presented a conceptual solution comprising four building blocks: Trust Assurance business model, network collaboration and governance framework, digital innovation, and technological and architectural support.

The paper introduced a preliminary implementation of the Trustworthiness-based Digital Innovation Hub (T_DIH) conceptual solution. This solution fosters trustworthiness in innovative smart solutions within the agrifood sector. The T_DIH provides a collaborative platform for stakeholders to engage in knowledge-sharing, learning, and assessment, promoting the adoption and evolution of trustworthy digital solutions.

Overall, by addressing these challenges and proposing innovative solutions, this paper contributes to advancing trustworthy evolution in agrifood technologies, paving the way for enhanced productivity, sustainability, and resilience in the sector. It provides the basis for continuing research and implementation efforts in the sector. It stimulates stakeholders to work together to build a more trustworthy and efficient agri-food ecosystem, benefiting farmers, consumers, and industry players.

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