EU Agristack: Promoting a European technology stack for agri-tech based on open-source

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1. Introduction

The digital transformation of agriculture is nowadays a priority for the European Union given its strategic role at the intersection of food security, technological competitiveness, and environmental sustainability. As geopolitical tensions reshape global technology markets and climate change pressures agricultural production systems, Europe's ability to develop and deploy its own sovereign digital technologies is critical to ensuring the long-term resilience of its productive sectors, including agriculture.

Despite investments in R&D over the past decade, EU agriculture continues to face structural challenges. While hundreds of digital solutions have been developed, their large-scale adoption is limited. This fragmentation reinforces strategic dependencies on non-European technologies and digital platforms. Addressing these challenges requires adopting an ecosystem approach capable of connecting existing solutions into coherent and interoperable technology value chains. Such an approach would facilitate technology reuse, strengthen industrial collaboration, and support the emergence of a sovereign agricultural tech ecosystem.

This white paper seeks to address this gap by mapping the agricultural tech landscape, highlighting key strengths and weaknesses, and suggesting practical steps towards a sovereign agricultural technology stack. Recent policy research efforts have strived to map key EU strengths and dependencies across the whole EU tech stack, suggesting large-scale policy actions (Bria et al. 2025). Zooming in on the agricultural sector, this document identifies and classifies the digital solutions developed through European initiatives, mapping them across the different layers of an EU AgriStack architecture from physical infrastructure to enabling, application, and transversal technologies. Building on this mapping exercise, the paper also performs a gap analysis to identify critical technological areas where Europe still displays dependency on non-European solutions. The results of the analysis allow the formulation of policy recommendations supporting a sovereign European digital ecosystem for agriculture.

2. EU agriculture tech policy context

2.1. Geopolitical scenario

Agriculture has become a strategic domain in the global technological race. Growing geopolitical competition, the acceleration of digital innovation and the pursuit of technological leadership are reshaping the way countries invest in critical technologies and strategic value chains. Alongside food security and ecological pressures brought by climate change and the need to scale up environmentally sustainable solutions, technological sovereignty has become a central objective for major global economies.

Within this context, Europe faces increasing pressure to strengthen its digitalisation capacity in key industrial sectors. Despite its world-class research base and leadership in several research areas, the European Union continues to lag behind competitors such as the United States and China in the development, commercialisation and large-scale adoption of digital technologies. Structural fragmentation, non-harmonised regulation and national approaches to industrial development have limited Europe's ability to scale technological solutions and create globally competitive digital ecosystems. Perhaps the best example of this dependency lays in the current European spending on proprietary IT products and services developed outside Europe, amounting approximately to EUR 264 billion annually (EC 2026). Overall, over 80% of digital technologies adopted in the EU are imported and EU firms represent only 7% of global R&D spending on software and internet technologies (Draghi 2024, Izsak et al. 2026).

At the same time, over the past decades, the European Union has funded hundreds of projects across R&D programmes, generating a substantial portfolio of digital technologies, software platforms, AI solutions, connectivity infrastructures, and data services. Many of these could potentially benefit several verticals, including the agri-food sector, strengthening productivity, resilience, and sustainability indicators. However, these solutions remain largely fragmented across projects, organisations and Member States, limiting their visibility, reuse and potential integration into a coherent European digital ecosystem.

In addition, European agriculture is facing unprecedented environmental pressures driven by climate change. Soil degradation, erosion, acidification, biodiversity loss and increasingly erratic weather patterns are already affecting agricultural productivity across the continent. Addressing these challenges requires technological solutions capable of supporting more efficient, resilient and sustainable farming practices while adapting to Europe's diverse environmental, climatic and socio-economic conditions.

2.2. Agri-tech challenges

Over the past decade, the European Union has made the modernisation of agriculture a strategic policy priority, mobilising regulatory, financial and research instruments to accelerate the uptake of digital technologies across the agri-food sector (EC 2023, Ciucci et al. 2025).

Among the main policy instruments, three have played a particularly important role:

- **The Common Agricultural Policy (CAP)** has supported investments aimed at integrating digitalisation into rural development programmes in precision farming technologies, farm modernisation, digital advisory services and knowledge transfer, while encouraging more sustainable and resource-efficient agricultural practices (EC 2023).
- **Cohesion Policy and regional development funds** have contributed to reducing territorial disparities by financing broadband deployment in rural areas, digital infrastructures, innovation ecosystems, European Digital Innovation Hubs (EDIHs) and capacity-building initiatives aimed at facilitating the adoption of advanced technologies by farmers and SMEs.
- **European research and innovation programmes**, including Horizon 2020, Horizon Europe and Digital Europe, have funded hundreds of projects developing cutting-edge solutions in artificial intelligence, robotics, Internet of Things, Earth Observation, data spaces, digital twins and autonomous systems. These programmes have significantly expanded Europe's technological capabilities and generated a rich portfolio of digital solutions that are increasingly available for deployment across the agricultural sector.

Despite these sustained efforts, the current state of technology adoption presents a mixed picture (Tur Cardona et al. 2025). Basic digital technologies have achieved widespread penetration across much of the European agricultural sector. Internet connectivity has improved considerably, smartphone ownership has become commonplace among farmers, and there is growing interest in crop-specific digital technologies together with software and mobile applications supporting agricultural activities. In addition, digital technologies are generally perceived as positive instruments capable of creating new business opportunities, improving regulatory compliance and strengthening farm resilience, particularly in response to the growing impacts of climate change.

However, the adoption of comprehensive digital farming approaches remains significantly lower. A clear gap exists between the widespread use of simple, general-purpose digital tools and the deployment of advanced farm-specific technologies. While software supporting resource monitoring, administrative management and commercial activities has experienced relatively broad uptake, more sophisticated solutions—including satellite-based monitoring services, Farm Management Information Systems (FMIS), unmanned aerial vehicles (UAVs), autonomous machinery and integrated monitoring platforms—continue to display comparatively low adoption rates. Moreover, despite the increasing reliance on digital tools, structural issues in rural connectivity infrastructures remain (Gil Mova 2026).

Economic considerations continue to represent one of the main barriers to technological adoption. Although expectations regarding the potential benefits of digital technologies are generally positive, affordability strongly influences investment decisions, meaning that advanced technologies are predominantly adopted by larger farms with greater financial resources. At the same time, limited willingness among farmers to participate in data-sharing practices—primarily due to concerns regarding privacy, ownership and the commercial use of agricultural data—constitutes another significant obstacle to the development of data-driven agricultural services (Tur Cardona et al. 2025). Technology adoption also varies considerably between Member States, agricultural sectors and farm typologies. Differences in farm size, production systems, access to finance, quality of digital infrastructures, availability of technological solutions and national support schemes all influence the pace of digitalisation (Eurostat 2025).

These variations demonstrate that digital transformation does not follow a uniform trajectory across Europe but is instead shaped by a combination of structural, economic and technological conditions. While Europe has invested substantially in the development of innovative digital technologies in agriculture, their uptake has not kept pace with technological progress. Closing this gap requires to primarily ensure that solutions developed through European initiatives become more accessible, affordable and interoperable. Rather than solely focusing on innovation, current policy efforts should focus on enabling Europe to fully capitalise on its investments in R&D to accelerate the digitalisation of agriculture.

2.3. Ecosystem approach to agri-food sovereignty

The technological and adoption gaps outlined in the previous sections clearly shift the current policy debate towards an ecosystem-level approach integrating the already-existing wealth of European technologies into value chains while identifying and reducing strategic dependencies on foreign providers. Such an approach consists primarily in mapping available capabilities, understanding critical technological gaps, and facilitating the adoption of indigenous alternatives.

This vision is reflected in current policy strategies for European competitiveness. Among these, the recently announced Sovereignty Tech Package leverages complementary European initiatives to simultaneously tackle different layers of the digital technology stack. These include:

- **The Chips Act 2.0 aims** at strengthening Europe's semiconductor ecosystem, increasing domestic chip production and reinforcing the resilience of critical semiconductor supply chains.
- **The Cloud and AI Development Act (CADA) is** designed to accelerate the deployment of European cloud and artificial intelligence infrastructures while reducing strategic dependencies on non-European providers.
- **The European Open Source Software Strategy promotes** the development and adoption of secure, interoperable and cyber-resilient open-source technologies as strategic digital public goods.

Among these initiatives, the European Open Source Software Strategy actively encourages the creation of collaborative ecosystems. Different actors (e.g. public administrations, research organisations, industry and open-source communities) should work together to jointly develop reusable digital building blocks deployable spanning the entire technology stack (e.g. chips, IoT, robotics, communication networks, cloud-edge computing infrastructures, DevOps, AI, cybersecurity and digital identity services). Making these solutions visible and reusable across sectors increases awareness of existing European capabilities, facilitates industrial partnerships and reduces duplication efforts (EC 2026).

The **EU AgriStack** model proposed in this document follows the same ecosystem-level approach. Rather than reinventing the wheel, it seeks to create a more coherent technological ecosystem for European agriculture. Such a task is accomplished by mapping the wealth of digital solutions already developed through European R&I programmes into a coherent technology stack spanning multiple application layers. This gap analysis also allows to identify remaining technological dependencies and capability gaps and produce relevant recommendations.

3. Agristack layers

The analysis presented in the previous chapter shows the current fragmentation of EU agri-tech initiatives and the potential impact of an ecosystem approach capable of connecting these individual assets into a coherent technological framework. The EU AgriStack proposed in this white paper organises agri-tech applications into a reference architecture (see Figure 1) across six main layers: physical (hardware and sensing), enabling (connectivity, data and intelligence), application (decision and automation) and transversal (market and regulatory. This reference architecture facilitates the identification of complementary technologies and allows to understand critical gaps and key dependencies.

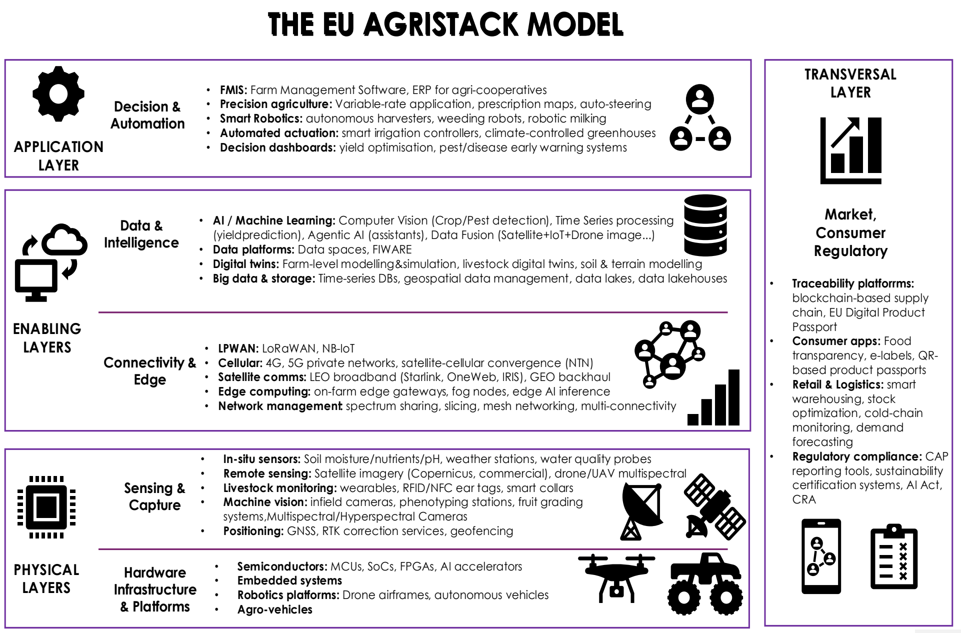

Figure 1. agristack model, source: AI-generated

The reference architecture was then populated through a mapping exercise which identified 199 open-source agri-tech solutions across all layers (Figure 2)**1** for more details about the methodology) This allowed the creation of a vast portfolio, including both complete agricultural digital solutions as well as individual technological components (see **Annex 1**)

[1] These were mainly taken from a copyright drawn from the OpenAgri project (Learn more at https://horizon-openagri.eu/) and then expanded by the authors of this document through complementary desktop research.

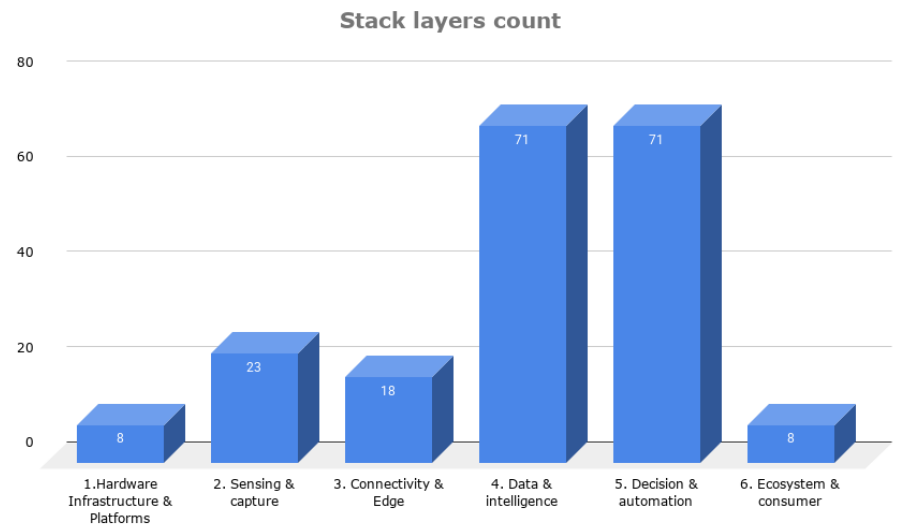

Figure 2. Aristack layers

The following sections present a mapping of available open-source technologies for each layer of the stack. This mapping exercise enables the identification of technological gaps and external dependencies while at the same time increasing the visibility and reuse of European technologies, fostering collaboration around open-source solutions. This repository is mainly focused on open-source solutions given their potential for uptake and reusability. As such, it is not an exhaustive catalogue, and limitations apply.

3.1. Hardware Infrastructure & Platforms

The Hardware Infrastructure & Platforms layer comprises the foundational physical technologies supporting digital agriculture. The mapped solutions include agricultural machinery, robotics platforms, hardware components and semiconductor technologies, providing the computing and operational infrastructure upon which higher layers of the AgriStack are built.

Figure 3 shows that the layer is largely dominated by agricultural machinery (6 out of 9 solutions), while robotics platforms, hardware components and semiconductor-related solutions are each represented by a single solution. This distribution suggests that the open-source ecosystem is primarily concentrated on machinery platforms, whereas lower-level hardware technologies remain comparatively scarce, reflecting the greater technological complexity and commercial value typically associated with proprietary hardware and semiconductor development.

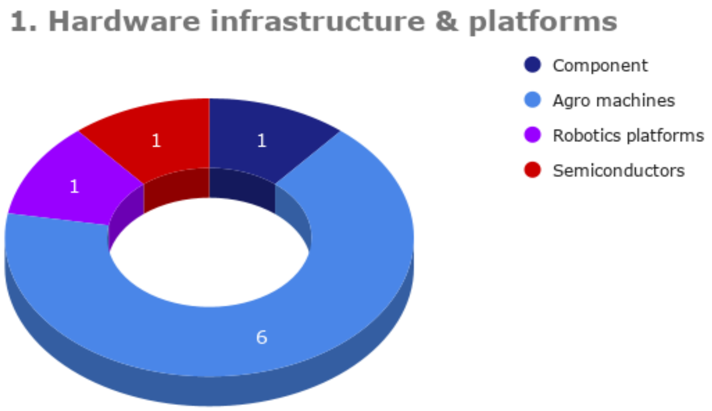

Figure 3. Layer 1: hardware infrastructure & platforms

3.2. Sensing & capture

The Sensing & Capture layer comprises technologies responsible for acquiring data from the physical environment. The mapped solutions include in-situ sensors, livestock monitoring systems, machine vision, mobile phenotyping applications and modular environmental data loggers, covering the main approaches used to collect field and livestock information for subsequent processing and analysis.

Figure 4 shows a strong predominance of in-situ sensing technologies (17 out of 23 solutions), while machine vision and livestock monitoring are represented by four and two solutions respectively. This distribution indicates that the open-source ecosystem is primarily focused on generating high-quality field data through sensor-based monitoring, whereas more specialised sensing technologies remain comparatively less represented.

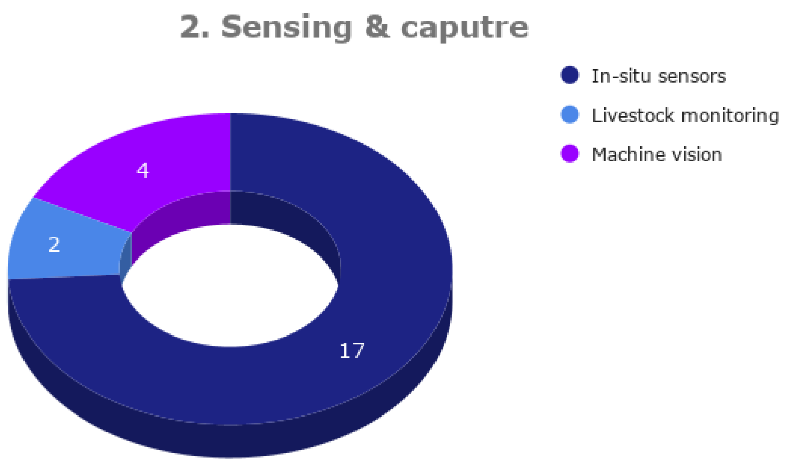

Figure 4. Layer 2: sensing & capture

3.3. Connectivity & Edge

The Connectivity & Edge layer comprises the technologies that enable communication between devices and the processing of data close to its source. The mapped solutions include low-power wide-area networking (LPWAN) technologies, network management platforms and edge computing frameworks, providing the infrastructure required to connect sensors, machinery and digital services across agricultural environments.

Figure 5 shows a relatively balanced distribution across the three sublayers, with LPWAN technologies accounting for seven solutions, followed by edge computing (six) and network management (five). This balanced representation suggests that the open-source ecosystem addresses the main components required for distributed agricultural connectivity, combining communication technologies with edge processing capabilities to support data-intensive and latency-sensitive applications in the field.

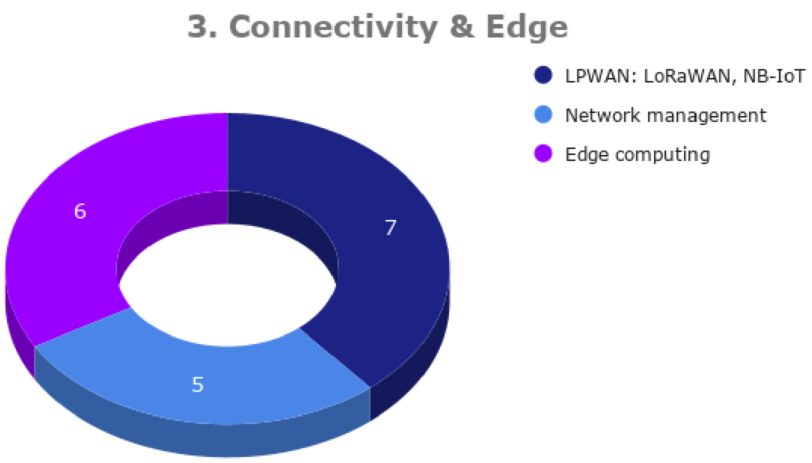

Figure 5. Layer 3: connectivity & edge

Data & intelligence

The Data & Intelligence layer comprises the technologies responsible for storing, integrating, and transforming agricultural data into actionable knowledge. The mapped solutions include data platforms, artificial intelligence and machine learning frameworks, digital twins, and big data and storage technologies, providing the core capabilities required for data management, modelling, and advanced analytics.

Figure 6 shows that data platforms constitute the largest category (29 solutions), followed by AI and machine learning (20), digital twins (12) and big data and storage (10). This distribution highlights the central role of interoperable data platforms within the open-source ecosystem, providing the foundation upon which AI models and digital twin applications can be developed and deployed. It also reflects the increasing maturity of open-source solutions supporting data-driven agriculture and intelligent decision-making.

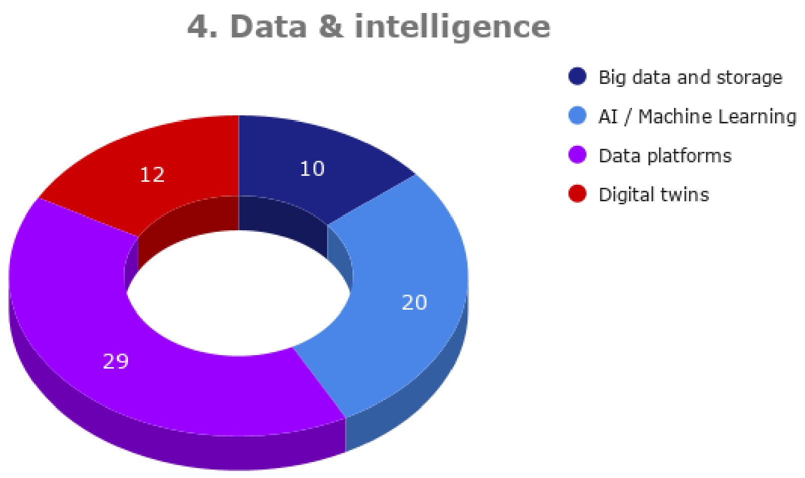

Figure 6. Layer 4: data & intelligence

3.4. Decision & automation

The Decision & Automation layer comprises the technologies that transform data into operational actions and support farm management. The mapped solutions include farm management information systems (FMIS), automated actuation, decision dashboards, precision agriculture applications and smart robotics, covering the main software tools used to assist or automate agricultural operations.

Figure 7 shows that automated actuation is the largest category (25 solutions), followed by FMIS (19) and decision dashboards (15). Precision agriculture accounts for nine solutions, while smart robotics is represented by only three. This distribution indicates that the open-source ecosystem is primarily focused on supporting data-driven farm operations through management software and automation technologies, whereas autonomous robotic applications remain comparatively less represented.

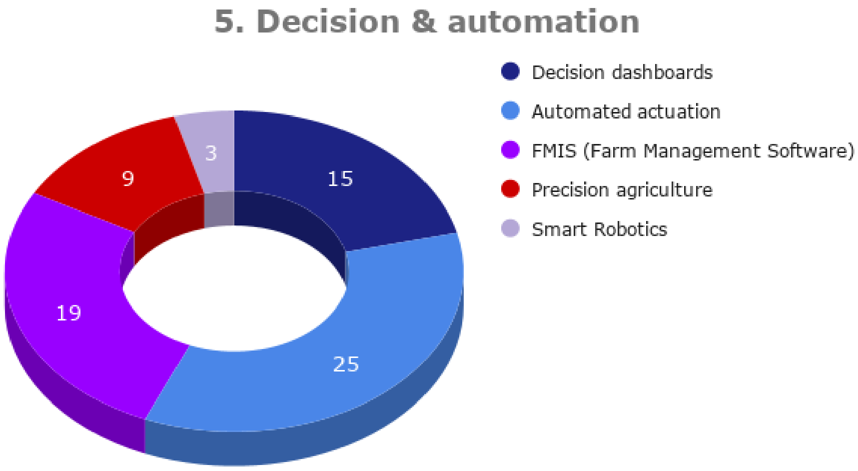

Figure 7. Layer 5: decision & automation

3.5. Market, Consumer & Regulatory

The Market, Consumer & Regulatory layer comprises technologies that connect farm-level digitalisation with downstream value chain services and regulatory requirements. The mapped solutions include traceability platforms, retail and logistics systems, consumer applications and regulatory compliance tools, supporting product transparency, supply chain management and compliance with European legislation.

Figure 8 shows a clear predominance of traceability platforms (five solutions), while retail and logistics, consumer applications and regulatory compliance are each represented by a single solution. This distribution suggests that open-source development in this layer has primarily focused on enabling product traceability across the agri-food value chain, whereas consumer-facing services and digital compliance solutions remain comparatively less developed.

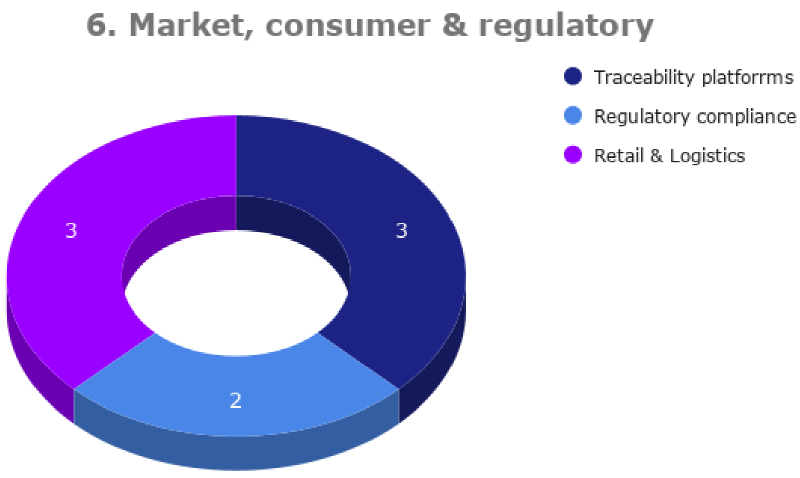

Figure 8. Layer 6: market, consumer & regulatory

4. Community engagement

In terms of active user engagement around the mapped solutions, a heterogeneous picture emerges (see Figure 3 below). Specifically, 70 solutions are associated with low community engagement, while 50 exhibit very high and 41 high levels of activity. Only three solutions are classified as having medium engagement, and for 35 solutions no community information was available. As community engagement is a key indicator of the adoption, maintenance and long-term sustainability of open-source software, these results reveal a dual landscape: alongside a core group of mature and widely adopted projects, there is a substantial number of solutions with limited or unknown levels of engagement. This suggests the existence of a significant but underexploited technological asset that could benefit from greater visibility, stronger communities and wider adoption.

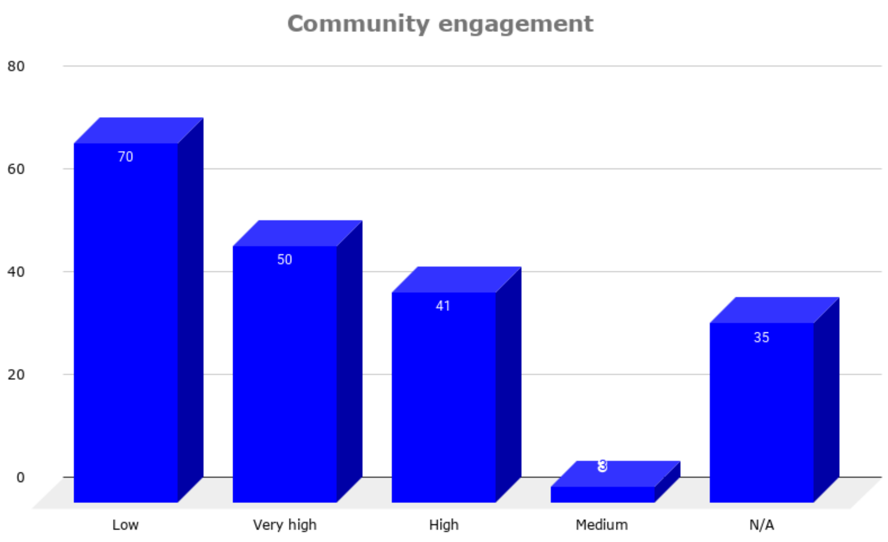

Figure 9. Community engagement metrics

Solutions exhibiting high and very high community engagement share several common characteristics. They are predominantly mature technologies (typically TRL 7–9) designed to address generic functionalities that can be reused across multiple agricultural sectors, crops and geographical contexts. Rather than being crop-specific applications, they mainly comprise enabling technologies and software components—including IoT platforms, data management frameworks, connectivity solutions, AI libraries, Farm Management Information Systems (FMIS) and interoperability tools—that serve as building blocks for more complex digital agriculture solutions. These projects are frequently maintained by well-established open-source communities, foundations or research organisations (e.g., FIWARE Foundation, Linux Foundation, Eclipse Foundation, Dronecode, QGIS and Hyperledger), rely on widely adopted open-source licences such as Apache, MIT and GPL, and support cloud, edge or hybrid deployment models. Their broad applicability, modular design and active developer communities make them suitable for integration into a wide range of digital agriculture applications, contributing to their sustained adoption and long-term evolution.

4.1. High community engagement

Solutions exhibiting high and very high community engagement share several common characteristics. They are predominantly mature technologies (typically TRL 7–9) designed to address generic functionalities that can be reused across multiple agricultural sectors, crops and geographical contexts. Rather than crop-specific applications, most of them comprise enabling technologies and software components including IoT platforms, data management frameworks, AI libraries, connectivity solutions, Farm Management Information Systems (FMIS) and automation tools that serve as building blocks for digital agriculture solutions. These projects are frequently maintained by well-established open-source communities, foundations or research organisations (e.g. FIWARE Foundation, Linux Foundation, Eclipse Foundation, Dronecode and QGIS), support cloud, edge or hybrid deployment models, and predominantly adopt widely recognised open-source licenses, such as Apache 2.0, MIT and GPL, complemented by BSD, AGPL and LGPL licences. The widespread use of these permissive and community-oriented licensing models facilitates code reuse, interoperability and external contributions, supporting the long-term sustainability of the projects.

As shown in Figure 10, the most active communities are concentrated in the Data & Intelligence layer, particularly around data platforms (22 solutions), followed by AI and Machine Learning (9), big data and storage (7), and digital twins (4). The Decision & Automation layer also exhibits strong community activity, especially for automated actuation, decision dashboards and FMIS, while Connectivity & Edge benefits from well-established communities supporting network management, edge computing and LPWAN technologies. In contrast, the Hardware Infrastructure and Market, Consumer & Regulatory layers contain relatively few highly engaged projects. Overall, community activity is concentrated around reusable software infrastructure and interoperability components that provide common capabilities for a wide range of digital agriculture applications.

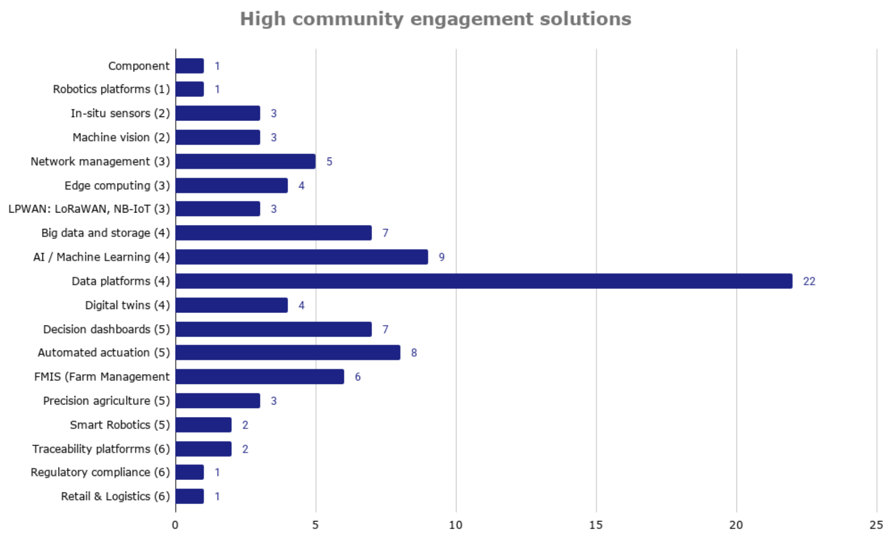

Figure 10. High community engagement solutions per type

4.2. Low community engagement

The low/medium/N/A group has a very different profile. Unlike the high-engagement solutions, these are mostly application-oriented projects, prototypes or niche tools, many developed by individual GitHub users, universities or short-lived research projects. Licensing is also less consistent: a considerable proportion either have no explicit license, is simply labelled as public code/open source, or uses a wide variety of licenses (GPL, MIT, BSD, CC-BY, CERN OHL, EUPL), making reuse and community contributions less straightforward in many cases.

As shown in Figure 11, solutions with low, medium or unavailable community engagement are concentrated in application-specific domains, particularly automated actuation (17 solutions), in-situ sensing (14), FMIS (13) and AI and Machine Learning (11). They also include a significant number of digital twins, decision dashboards and data platforms, while hardware and market-oriented solutions remain comparatively limited. A substantial share of the N/A solutions corresponds to outputs of European research projects (e.g., OpenAgri, QuantiFarm and FarmVibes) or community repositories where information on community activity is not publicly available. Taken together, these results suggest that a considerable number of technically valuable solutions have not yet developed active user and developer communities or are insufficiently visible to assess their level of adoption, representing a potentially underexploited asset that could benefit from greater dissemination, coordination and ecosystem support.

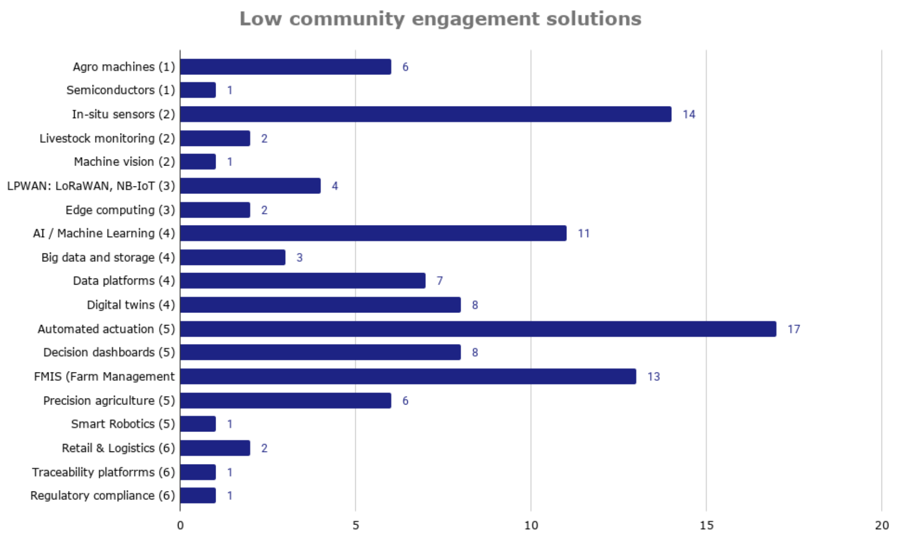

Figure 11. Low community engagement solutions per type

5. Interoperability frameworks

The mapping of relevant solutions for EU agriculture was complemented by a collection of relevant standards. While open-source software provides reusable technological building blocks, standards define the common interfaces, communication protocols, semantic models and governance rules. This is particularly important in agriculture, where digital ecosystems integrate heterogeneous devices, platforms and services deployed by multiple vendors and organisations. Without widely adopted standards, the benefits of scalability offered by open-source technologies cannot be fully realised.

The mapping exercise performed in this document identified a broad ecosystem of relevant standards developed by standardisation organisations (see Annex 2). Open and publicly accessible standards are particularly well represented through organisations such as ETSI, OGC, FIWARE and IEEE, which provide specifications for semantic interoperability, IoT communication, data exchange, geospatial services and distributed systems. Alongside these, international and European standardisation bodies such as ISO, IEC and CEN-CENELEC play a complementary role by defining harmonised standards for agricultural machinery, functional safety, artificial intelligence, cybersecurity and regulatory compliance.

Figure 12 illustrates the distribution of the mapped standards across the Agristack. The largest concentration is found in Connectivity & Edge (40 standards) and Data & Intelligence (32), reflecting the central importance of communication protocols, semantic interoperability, IoT architectures and data exchange models for integrating heterogeneous digital systems. In contrast, comparatively fewer standards were identified in Hardware Infrastructure & Platforms (4) and Decision & Automation (4), where standardisation efforts tend to focus on specific technologies such as robotics and machinery safety. The Market, Consumer & Regulatory layer accounts for 11 standards, largely addressing traceability, cybersecurity, distributed ledger technologies and regulatory compliance. Overall, the distribution confirms that standardisation efforts are primarily concentrated on enabling interoperability between technologies, reinforcing the role of connectivity and data exchange as the backbone of an open and modular Agristack.

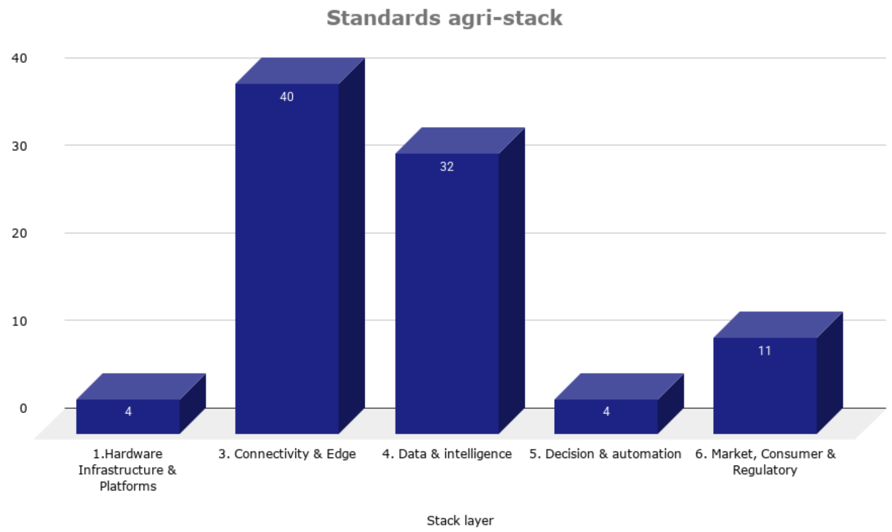

Figure 12. agristack standards per layer

5.1 Cross-SDO interoperability across the AgriStack

Interoperability within the EU AgriStack should be considered across several complementary levels rather than as a single technical property. At the architectural level, reference architectures such as ISO/IEC 30141 and oneM2M provide common concepts and functional decomposition for IoT systems. At the semantic level, frameworks such as ETSI SAREF and its agricultural extensions support the consistent description of devices, observations and domain concepts. At the interaction level, specifications such as W3C Web of Things provide mechanisms for describing and accessing heterogeneous connected assets. Finally, trust, provenance and accountability mechanisms can complement these layers by enabling verifiable evidence concerning the origin and processing of agricultural data.

A major challenge is therefore not the absence of standards, but the lack of commonly agreed interoperability profiles defining how standards originating from different SDOs should be combined in concrete agricultural deployments.

Table 1. Relevant standards

Interoperability concern	Relevant standards/frameworks	AgriStack role
Reference architecture	ISO/IEC 30141, oneM2M TS-0001	Sensing → Edge → Data architecture
Semantic interoperability	ETSI SAREF / SAREF4AGRI	Shared meaning of devices/data
Device/service interaction	W3C WoT	Interoperable exposure/discovery of assets
Security	oneM2M TS-0003	Authentication and secure IoT services
Provenance/accountability	IETF SCITT / DLT mechanisms	Verifiable records across the value chain

6. Gap analysis & dependency mapping

The mapping exercise demonstrates the availability of a broad portfolio of open-source technologies covering virtually every layer of the AgriStack. However, technological availability alone does not translate into technological sovereignty. The analysis reveals several structural gaps that continue to limit the deployment of a coherent European agricultural digital ecosystem. These gaps relate not only to missing technologies but also to fragmentation, insufficient industrial adoption, weak open-source communities, dependence on non-European platforms, and the absence of common integration mechanisms. Consequently, Europe's challenge is less about inventing new technologies than about transforming existing assets into an interoperable and scalable ecosystem capable of providing viable alternatives to integrated proprietary platforms.

- **Uneven maturity across the stack:** the mapping reveals an uneven distribution of open-source solutions across the different layers of the AgriStack. Connectivity, data management and decision-support technologies are represented by a broad range of mature and reusable projects supported by established communities and interoperability standards. In contrast, comparatively fewer open-source solutions were identified in areas such as hardware infrastructure, robotics, autonomous systems and market-facing applications.
- **Fragmentation of the ecosystem:** the mapping identified a wealth of open-source solutions covering similar functionalities across the AgriStack. However, many have been developed independently within research and innovation projects, resulting in overlapping capabilities, limited reuse and few common reference implementations.
- **Community sustainability:** open-source sustainability emerges as another important gap. While approximately half of the mapped solutions exhibit high or very high community engagement, a substantial proportion shows limited activity or lacks publicly available community information. The most active projects are generally mature enabling technologies maintained by large foundations such as FIWARE, Eclipse, Linux Foundation, or QGIS. In contrast, many application-orient~~at~~ed solutions developed through European R&I projects have small communities, inconsistent licensing practices and uncertain long-term maintenance.
- **Dependence on foundational digital infrastructures:** the mapping shows that many agricultural solutions mapped here rely on mature generic technologies developed outside the agricultural domain, including hardware devices, cloud-native platforms, AI frameworks, databases, developer tools and operating systems. This is a natural characteristic of modern software ecosystems, where foundational digital infrastructures are located outside of EU borders.
- **Interoperability remains incomplete:** the standards mapping shows that Europe benefits from a rich interoperability ecosystem, particularly around connectivity, semantic data exchange and IoT architectures. Nevertheless, the existence of standards does not automatically guarantee the interoperability of solutions developed by different projects and organisations. Building a European AgriStack therefore requires not only defining standards but also ensuring their widespread implementation through open-source reference software.

- **Missing ecosystem layer:** most mapped solutions address specific technological domains within the AgriStack, while comparatively few provide end-to-end integration across multiple layers. Unlike major proprietary ecosystems, there is no common toolbox facilitating the search and integration of such functionalities.
- **Trust and provenance across stack layers:** Existing interoperability mechanisms primarily address connectivity, data models and service interfaces, but comparatively less attention is given to maintaining verifiable provenance as information moves from sensing devices and edge systems towards data platforms, decision-support systems and downstream supply-chain actors. Agricultural applications involving certification, traceability or regulatory compliance require mechanisms capable of linking observations and processing steps to identifiable sources while preserving integrity and auditability. DLT and transparency technologies can complement existing IoT standards in this area, provided that common integration patterns are defined.

Table 2. Gap analysis and implication summary

Gap	Mapping evidence	Main implications	Affected areas
Uneven coverage across the stack	Open-source activity is concentrated in connectivity, data management and decision-support technologies	Some parts of the stack offer reusable alternatives, whereas others remain dependent on a narrower set of solutions	Hardware Infrastructure; Decision & Automation; Market, Consumer & Regulatory
Fragmentation of the ecosystem	Numerous projects provide overlapping functionalities but have been developed independently, with limited common reference implementations	Similar capabilities are repeatedly developed without forming a coherent ecosystem	All layers, particularly Data & Intelligence and Decision & Automation
Community sustainability	A substantial share of solutions have low community engagement, while the strongest communities are concentrated around established enabling technologies	Technically relevant solutions may become difficult to maintain, reuse or evolve after their original development cycle	Sensing & Capture; Data & Intelligence; Decision & Automation
Dependence on foundational infrastructures	Many agriculture-specific solutions rely on generic ecosystems developed outside the agricultural domain	The availability and evolution of agricultural applications depend on foundational technologies	Hardware Infrastructure; Connectivity & Edge; Data & Intelligence; Decision & Automation
Incomplete interoperability	A broad range of standards exists, but their implementation remains uneven across projects and platforms	Compliance with different standards does not ensure the integration of independently developed components	Connectivity & Edge; Data & Intelligence; Decision & Automation
Missing ecosystem layer	Most solutions address individual functions or stack components, while relatively few provide mechanisms for discovering and combination	Existing building blocks remain difficult to identify, compare and assemble into complete agricultural digital workflows	Transversal across all layers

Trust, provenance and verifiable data exchange	Existing interoperability mechanisms primarily address connectivity, data models and service interfaces, while end-to-end provenance and verifiable evidence across sensing, edge, data platforms and downstream actors remain comparatively underdeveloped.	Agricultural data used for traceability, certification, AI-based decision making and regulatory compliance may lack verifiable evidence regarding its origin, processing history and integrity.	Sensing & Capture; Connectivity & Edge; Data & Intelligence; Market, Consumer & Regulatory.

7. Policy recommendations

Commented [1]: All: please provide suggestions for potential recommendations (bearing in mind the content of our analysis)

Europe's challenge is no longer the generation of agricultural digital technologies but their integration into a coherent, interoperable and sustainable ecosystem. Policy should therefore move beyond funding isolated innovation projects towards governing and maintaining shared digital commons. A European AgriStack initiative, built on open-source enabling technologies, interoperable standards and long-term community support, would strengthen the competitiveness, resilience and strategic autonomy of the European agri-food sector while maximising the return on previous public investments in R&I, without undermining the benefits of international open-source collaboration.

EU Tech Sovereignty initiatives like Chips Act 2.0 or CADA are transversal to all economic sectors, as they focus on foundational digital infrastructures. Open-source HW approaches like RISC-V should be encouraged. Instead of creating agriculture-specific substitutes, the objective should be to ensure that agriculture becomes an important early adopter of strategic European digital infrastructures.

We propose to design a **European Open-Source AgriStack Industrial and Policy Agenda**, with specific measures for the agriculture sector that could include the following. :

- Implement a **Digital European Agristack EDIC** (Digital Commons EDIC to advance Europe's technological sovereignty[2]
- Prioritise domains where strategic gaps have been identified, like HW, robotics and autonomous systems.
- Develop a **European Agristack Marketplace** with open-source agri-tech building blocks. To ensure long-term sustainability, EU programmes should incentivise the reuse and evolution of existing components instead of developing new solutions Publicly-funded projects producing open-source assets should provide a sustainability and exit plan after the funded project ends. Where appropriate, mature outputs should be transferred to established European open-source foundations or long-term sectoral communities.
- Connect the Agristack with the existing network of **agrifood Testing and Experimentation Facilities** through common validation methodologies and open conformance-testing tools that could eventually lead to an **Agristack Certification and Compatibility Framework**, reducing integration risk for technology providers and users.
- **Develop AgriStack interoperability profiles.** Rather than creating additional standards, European initiatives should define implementation profiles identifying compatible combinations of existing specifications for recurring agricultural scenarios. Profiles should cover reference architecture, connectivity, semantics, security and trusted data exchange, and should be accompanied by open-source reference implementations and interoperability tests.
- **Introduce end-to-end provenance and trust patterns.** Agricultural data used for certification, traceability, AI-based decision-making and regulatory reporting

[2] https://digital-strategy.ec.europa.eu/en/news/digital-commons-edic-launches-advance-europes-technological-sovereignty

should be accompanied by machine-verifiable provenance information. European AgriStack reference implementations should investigate the combination of IoT standards with cryptographic transparency and DLT mechanisms to provide verifiable evidence from data acquisition to downstream use.

- **Launch large-scale cross-border deployment pilots.** Support a limited number of high-impact demonstrators integrating components from several AgriStack layers in operational agricultural value chains. Priority should be given to use cases with clear European added value, such as climate adaptation, regulatory reporting and agri-food traceability.
- This would enable the European agri-food sector to adopt advanced digital technologies under conditions that preserve choice, portability and control, while strengthening European competitiveness, resilience and strategic autonomy. The next step should be to translate this vision into a coordinated implementation roadmap, with clear governance, measurable milestones and shared responsibilities across European, national and regional actors.

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