Pathways towards a fair, inclusive and innovative Data Economy for Sustainable Food Systems

D1.2: Drivers and barriers of the Data Economy for Food Systems

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Data4Food2030 Consortium

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Glossary of terms and abbreviations

List of Abbreviations and Acronyms	
AI	Artificial Intelligence
B2G	Business-to-Government
CAP	Common Agricultural Policy
CS	Case study
DAT	Digital Agricultural Technologies
DE4FS	Data Economy for Food Systems
EC	European Commission
EU	European Union
FLW	Food Waste and Loss
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
IoT	Internet of Things
PESTEL	Political, Economic, Social, Technological, Environmental and Legal
SRL	Society Readiness Level
TRL	Technology Readiness Level

Executive Summary

This deliverable explores the drivers and barriers shaping the emerging Data Economy for Food Systems (DE4FS), based on the literature, case studies, and stakeholder dialogues. It provides an integrated analysis across three interrelated dimensions critical to the development and implementation of DE4FS: (i) European strategies and regulatory frameworks, with particular focus on data ownership; (ii) current and emerging business models relevant to DE4FS; and (iii) the Societal Readiness Level (SRL) required for the effective adoption of DE4FS.

Analytical framework
The DE4FS is conceptualised as a dynamic, multi-actor ecosystem that integrates data, knowledge, and digital services with the material dimensions of food production, processing, distribution, and consumption. It is characterised by complex interactions, evolving boundaries, and strong connections to societal values such as sustainability, fairness, inclusiveness and health.

The analysis reveals that drivers and barriers in DE4FS are highly context-dependent and shaped by the political economy of data, stakeholder perspectives, institutional arrangements, and varying levels of trust and inclusiveness. Rather than purely technical constraints, many barriers stem from governance, organisational culture, fragmented infrastructures, or regulatory ambiguity. Likewise, enabling drivers include trusted relationships, supportive institutions, shared value creation, and locally embedded digital innovation.

Using a multi-method approach, this deliverable outlines a mapping of drivers and barriers across the PESTEL dimensions (Political, Economic, Social, Technological, Environmental, and Legal), and links these with DE4FS-specific dimensions such as data governance, value co-creation, interoperability, data fairness, and inclusiveness. A key insight is that competing values and claims in food systems e.g., between openness and privacy, efficiency and equity, or standardisation and local specificity, underpin many of the tensions experienced in practice.

European strategies and regulatory frameworks
In terms of regulation and EU strategies, the deliverable finds that while instruments like the GDPR and Data Act aim to create safeguards and trust, they can also be experienced as burdensome or unclear by certain stakeholders. The conclusion calls for clearer, more food-system-specific guidance on how general-purpose data legislation applies, alongside sustained support for co-creation of policy and innovation. The analytical framework facilitates the evaluation of EU regulations and strategies for the DE4FS through the lens of SRL dimensions (awareness, capacity, legitimacy, and willingness).

Business models relevant to DE4FS
As food systems become increasingly digitalised, data has emerged as a strategic resource driving new business models. Literature, case studies, and stakeholder input reveal four dominant value creation mechanisms: selling raw data, selling intelligence, selling data-based products or services, and using data for governance purposes. The study also identifies emerging directions for data-enabled business models that promote more equitable value distribution, particularly for primary producers. While promising, these models remain underdeveloped and require investment, experimentation, and structural support to become viable alternatives to dominant platform-driven approaches.

Societal Readiness Level (SRL)
In this deliverable, we interpret SRL as the degree to which society is ready to adopt and adapt to a systemic innovation like DE4FS. SRL is highly context-dependent, with trust and perceived value being just as important as technical maturity. Stakeholders may withhold participation not due to a lack of digital capability, but due to concerns about data misuse, exclusion, or lack of benefit-sharing. Moreover, inclusiveness must also mean respecting the right to opt out; a perspective grounded in data sovereignty and responsible innovation literature.

Achieving a higher level of SRL requires more than a one-size-fits-all digital transformation strategy. Instead, it calls for adaptive governance, co-creation with affected communities, and the development of both qualitative and quantitative metrics to monitor trust, data equity, and social impact over time, while also developing strategies and tools to strengthen trust and enhance perceived value.

Recommendations and next steps
EU Strategies & Regulation: Clarify how horizontal digital strategies and legislation (e.g., GDPR, Data Act, and the European Digital Strategy) applies to food system contexts. Explicitly link these to food-focused policy frameworks such as the EU Food 2030 strategy, particularly the 'data and digital transformation' pathway for action to transform food systems. Co-develop regulatory sandboxes to test inclusive governance approaches.

Business models: Promote the development of diverse business models that embed data-sharing principles such as reciprocity, transparency, and fair benefit distribution. These models should not be limited to intermediaries but should be integrated across the full range of actors that include primary producers, SMEs, cooperatives, service providers, and agri-food platforms, to support the inclusive growth of the DE4FS.

SRL Development: Assess and track current status of societal readiness using the assessment framework. Embed the assessment into project evaluation and policy impact assessments.

Policy-science integration: Link SRL assessments to policy design processes, ensuring that digital innovation aligns with broader societal goals such as food justice, ecological sustainability, and resilience.

This deliverable concludes that the DE4FS has the potential to generate significant public and private value, but only if its development is approached as a social as well as technical transformation, grounded in equity, transparency, and democratic oversight.

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1 Introduction

1.1 Background and objective

The digital transformation of food systems has reached an uncertain stage: while data-driven innovations show great promise, scaling their adoption and achieving widespread acceptance remains a challenge. Against this backdrop, there is growing interest in the Data Economy for Food Systems (DE4FS), which broadly refers to the production, flow, sharing, and use of data as a key economic resource.

The Data4Food2030 project seeks to strengthen the DE4FS by broadening its definition, tracking its evolution, performance, and impact, and uncovering new insights and opportunities. More specifically, the project aims to contribute to a more sustainable, fair and inclusive data-driven transformation of food systems by supporting the development of a well-functioning DE4FS. The project's approach focuses on identifying and promoting design principles, actionable recommendations, and practical solutions to inform and enhance policies and practices at both public and private levels. To support this ambition, Work Package 1 (WP1) of the project was tasked with establishing an open and interdisciplinary knowledge base on the DE4FS. WP1 consists of five tasks and this deliverable presents the result of Task 1.4.

Task 1.4 aims to generate knowledge on three interrelated dimensions that are essential for the development and implementation of a DE4FS: (i) the analysis of current and emerging business models in the context of DE4FS; (ii) the interpretation of European strategies and regulatory frameworks, with particular emphasis on data ownership; and (iii) the assessment of SRL for the uptake of DE4FS. The analysis is informed by empirical developments from WP2, WP3 and WP4.

1.2 Content of this deliverable

This deliverable contributes to the Data4Food2030 project by providing a structured analysis of the drivers and barriers influencing the development of the DE4FS. Chapter 2 presents the methodological approach, combining an initial analytical framework with a desk study and multi-stakeholder consultations. In Chapter 3, the results are organised around several core components: the conceptualisation of DE4FS (Section 3.1.1), its impact on business models (3.1.2), and the relevance of SRL as a means to assess inclusiveness and trust in data innovation (3.1.3). Chapter 3 also addresses the implications of EU strategies and regulations (3.2), current business model dynamics (3.3), and presents a structured overview of drivers and barriers to the DE4FS (3.4), followed by a preliminary assessment of SRL (3.5).

In Chapter 4, the discussion turns to broader political and normative considerations, including competing claims and values in food systems (4.1), the political economy of data (4.2), and the multifaceted nature of the DE4FS (4.3). It further highlights the context dependency of drivers and barriers (4.4) and the importance of inclusiveness, also understood as the right to opt out (4.5), culminating in a reflection on the need for reflexive and adaptive governance (4.6). Finally, Chapter 5 offers conclusions and next steps, with recommendations for EU regulatory strategies (5.1), data-enabled business models (5.2), and the further development of SRLs (5.3). Together, this deliverable provides a conceptual, empirical, and policy-oriented foundation for navigating the complex landscape of data innovation in food systems.

2 Methodology

2.1 Overall approach

This chapter outlines the methodological approach adopted to carry out Task 1.4 in the Data4food2030 project, structured around three main components: (1) desk research; (2) stakeholder consultation; and (3) analysis. Central to this approach is the iterative development and refinement of an analytical framework for drivers and barriers of the DE4FS. The methodology aims to provide a robust, evidence-based understanding of DE4FS, their business models, and the contextual drivers and barriers shaping their evolution. It is specifically designed to address the following research questions:

- What are the key factors influencing the development and adoption of DE4FS and how do they shape its trajectory? (based on desk study and stakeholder feedback)
- What are the leading business models and governance arrangements driving DE4FS and what are the drivers and barriers affecting them? (based on desk study and feedback from case studies)
- How can these factors be influenced by policy? (explored through a review of relevant EU policy frameworks, complemented by stakeholder dialogues and case study insights, to identify actionable policy levers and governance mechanisms.

2.2 Initial analytical framework

Based on the conceptual frameworks described in D1.1, the initial analytical framework[3] is designed to explore the drivers and barriers shaping the development of DE4FS using a layered approach. This framework is applied through a combination of desk research, analysis of case studies, and stakeholder dialogues to ensure a comprehensive and context-sensitive understanding. It integrates five core components as identified in the conceptual framework for DE4FS: 1) the enabling environment; 2) data ecosystem infrastructure; 3) market and economic mechanisms; 4) socio-cultural and behavioural factors; and 5) environmental and sustainability goals. These components are analysed across three levels: macro (global/EU/national), meso (institutional/regional), and micro (local/farm-level) to capture the complexity of DE4FS and its system interactions.

In addition to the layered approach, the initial framework adopts a multidimensional lens, incorporating technical, economic, political-institutional, social-ethical, and environmental dimensions to assess how various factors facilitate or hinder data-driven innovation. It serves as a foundation for identifying key enabling factors, business models, governance arrangements, and policy levers that can influence the fair and inclusive development of DE4FS. This initial version was iteratively refined through desk research and stakeholder engagement to ensure contextual relevance and analytical rigor.

[3] A conceptual framework defines the key concepts, theories, and presumed relationships that guide a study's overall orientation. It outlines what is being studied and why, drawing from existing literature and theoretical models. In contrast, an analytical framework translates these concepts into operational tools for empirical analysis, specifying how data will be collected, organised, and interpreted. While the conceptual framework offers the "why" and "what," the analytical framework provides the "how."

2.3 Desk research

The desk study constitutes the foundational research phase of the task. It aims to gather, synthesise and analyse existing knowledge from academic literature, policy documents, project deliverables (including draft versions), industry reports, and other grey literature.

The literature review conducted under Task 1.4 follows a structured and multi-source approach to ensure comprehensive coverage of academic, legal, and policy-relevant knowledge domains related to the DE4FS. The review draws on both peer-reviewed academic literature and grey literature (including case study reports within this project) to capture the full spectrum of insights and developments in this rapidly evolving field. Academic sources are identified through systematic keyword searches using databases such as Google Scholar and Scopus, with search terms including but not limited to: “data economy,” “digital agriculture,” “data sharing business models,” “data governance in food systems,” “farm-level data ownership,” and “societal readiness for digitalisation.” In parallel, the review incorporates grey literature from relevant EU institutions, national authorities, NGOs, and research networks. This includes regulatory texts (e.g. the Data Act, Data Governance Act, GDPR), European Commission strategy papers, project deliverables from Horizon 2020/Europe initiatives, and reports by organisations such as the OECD, FAO, EIP-AGRI, and EU digital innovation hubs. Documents are screened for relevance, credibility, and timeliness (i.e., their currency or actuality). A snowballing method is applied where relevant, allowing the inclusion of further pertinent materials through reference tracing. The review is organised around three core dimensions: business models, regulatory frameworks, and societal readiness. The findings were synthesised into summaries to identify knowledge gaps, drivers and barriers, and policy implications relevant to DE4FS development and uptake.

This work was focused on addressing the following topics related to the research questions:

- **Key features of DE4FS**: Identification and elaboration of the defining features of DE4FS as described in D1.1, case studies and stakeholder dialogues, with a focus on how these features influence both existing and emerging business models.
- **Relevant EU strategies and regulations**: Mapping and analysis of European Union strategies, directives, and regulatory frameworks that impact or support DE4FS development, including those related to data production, data governance, digital innovation, food system transformation, sustainability, and ethics.
- **Business models in the data economy**: Review of the predominant business models used in the broader data economy, with specific attention to their applicability, adoption, and adaptation within DE4FS contexts.
- **Social aspects**: Exploration of key social dimensions, including political, ethical, and legal considerations that shape stakeholder perceptions, acceptance, and the broader societal embedding of DE4FS.
- **Drivers and barriers**: Identification of enablers and obstacles influencing the development and implementation of business models in DE4FS. This includes a comprehensive PESTEL (Political, Economic, Social, Technological, Environmental, and Legal) analysis to capture a wide range of influencing factors, including governance structures.

Insights from the desk research also served to refine the analytical framework, which guided subsequent stakeholder engagement and empirical analysis.

2.4 Stakeholder consultation

To complement the desk research, the methodology integrates a stakeholder consultation process to gather qualitative, real-world insights from relevant actors within the DE4FS ecosystem. This includes empirical work across WPs. Feedback on the analytical framework and analysis has been collected either directly through meetings or indirectly through deliverables and working documents from WP2, WP3, and WP4. These work packages engage with various stakeholder groups including food producers, data providers, policymakers, researchers and civil society representatives, ensuring diversity in perspectives and contexts.

In addition to targeted engagements within the WPs, a series of online, interactive workshops was organised. The interactions with case studies were facilitated through the interactive tool Wooclap[4] designed to capture stakeholder input and foster dynamic engagement. Figure 1 illustrates how the tool was employed to gather insights and stimulate collaboration throughout the project.

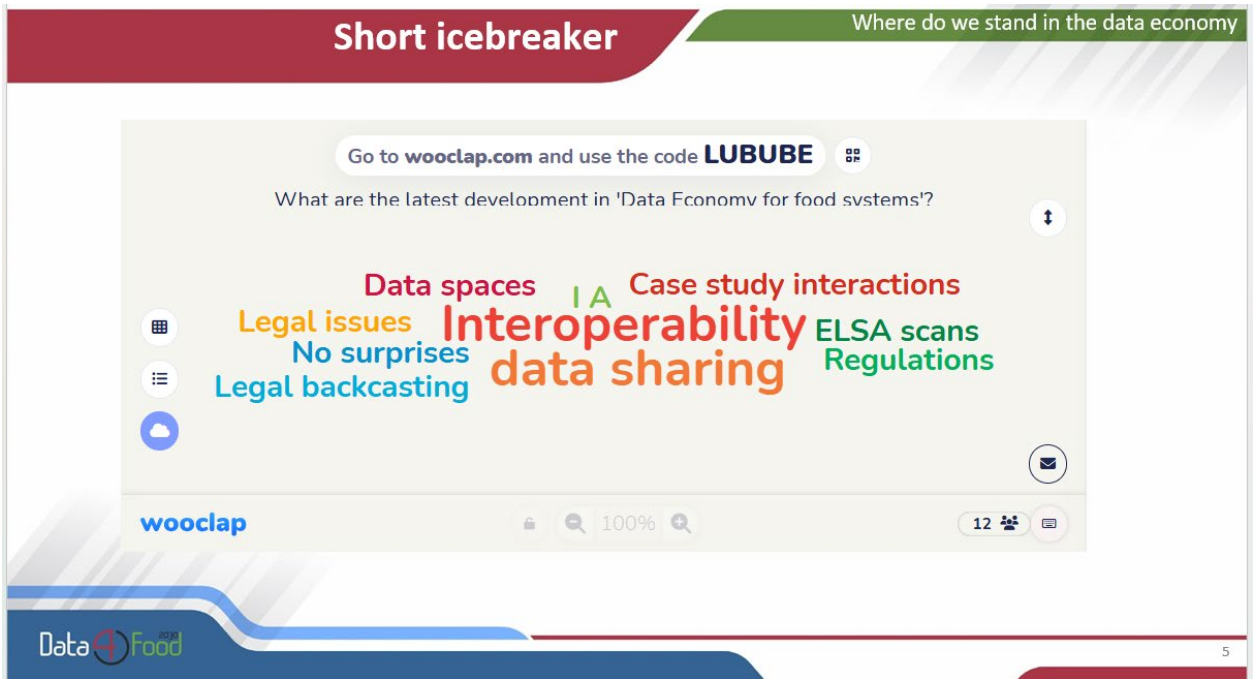

Figure 1 Slide used during the workshop on business models in the data economy

2.5 Analysis

The analysis phase refines the analytical framework and integrates findings from desk study and stakeholder consultation activities. Key steps included: 1) Synthesis of evidence: Cross-comparison of insights from literature and empirical data to validate and refine the analytical framework; 2) Typology development: Formulation of a typology of business models relevant to DE4FS, accounting for their enabling conditions, sectoral focus, and alignment with EU policy goals; 3) Assessment of drivers and barriers: Evaluation of how different drivers and barriers affect

[4] See more information on Wooclap at: Foster engagement with Wooclap's interactive presentations

the feasibility and performance of business models and SRL of DE4FS, supported by PESTEL mapping and stakeholder feedback; 4) Policy recommendations: Based on the analytical outcomes, targeted recommendations will be formulated to support the transition to a fair, inclusive and innovative DE4FS.

3 Results

3.1 Analytical framework for analysing drivers and barriers of DE4FS

3.1.1 Conceptualisation of DE4FS

As described in D1.1 and observed in the case studies (WP3) and stakeholder dialogues (WP4), the concept of a 'data economy' is multifaceted, dynamic, and subject to ongoing interpretation. It is defined in varying ways across academic literature and is applied differently in practice, depending on context, time, and stakeholder perspective. As a result, defining a 'Data Economy for Food Systems' is not a static exercise, but rather an iterative and evolving process. It reflects a progressively deepening and widening understanding of how data, digital infrastructure, and value creation intersect within agri-food systems.

For this deliverable, the conceptualisation of DE4FS is built upon the latest definition (updated in March 2025 by T1.1) as follows:

The DE4FS is a dynamic ecosystem that supports direct and indirect interactions between the Data Economy and the Food System. The DE4FS is characterized by numerous and evolutive sub-ecosystems with loosed boundaries, defined based on preexisting knowledge, models, specific temporalities and spatialities, and in relation to societal expectations, such as ethics, fairness, inclusiveness, food security, sustainability.

The DE4FS is deployed by means of immaterial resources, such as data, skills, competences and knowledge, applied to material resources by its actors, organized through profit and not-for-profit relationships and formal and informal interactions, and regulated by institutional and legal arrangements.

By integrating material and immaterial resources from within and outside its own ecosystem, the DE4FS is a source of value co-creation for its stakeholders, other related ecosystems such as health, technology, research and innovation… and the society at large.
The DE4FS value co-creation process aims at reducing the temporality and spatiality of specific food systems, by mobilizing data-driven solutions that provide real-time and located information supporting decision-making and monitoring, and at fostering their functioning and evolution. The DE4FS value co-creation involves monetary exchanges but also non-monetary service exchanges related to the use of the data-driven solutions and the context in which they are developed, including societal expectations, natural constraints, existing regulations, and stakeholders' demands.

From this rich and systems-oriented definition of the DE4FS, several important implications for analysing drivers and barriers can be derived. These implications go beyond technical aspects and highlight how complex, evolving, and socially embedded the DE4FS is. First of all, an implication is that drivers and barriers can be identified or examined through multiple lenses. For example, they can be categorized thematically (e.g. legal, social, technological) or functionally (e.g. enabling conditions, barriers, expected outcomes), reflecting the layered nature of the DE4FS ecosystem.

Secondly, drivers and barriers are context-dependent and may shift across time and space. What facilitates value creation in one moment or sub-ecosystem may act as a barrier in another. This calls for a dynamic and flexible approach that acknowledges temporalities, spatialities, and sectoral specificities.

Thirdly, drivers and barriers are often entangled with societal expectations and institutional logics. For instance, regulatory measures or ethical norms may act as both enablers of trust and constraints on innovation, depending on how they are interpreted and implemented within specific stakeholder constellations.

Finally, the analysis should recognize that drivers and barriers do not operate in isolation. They interact, sometimes reinforcing each other, sometimes creating tensions. Understanding these interactions is crucial for identifying leverage points for intervention and coordination across the DE4FS and adjacent ecosystems (e.g. health, research, technology).

3.1.2 Impact of DE4FS on business models

When it comes to business models in the DE4FS, the first area of investigation concerns the identification and characterisation of the related business models (existing and new ones)that describe how various actors in food systems create, deliver, and capture value through the production, use and exchange of data. The emphasis lies on models in which data and the broader data ecosystem plays a central role in shaping economic and social interactions that result in value creation and distribution. This includes both existing models currently in use within the agri-food sector and novel configurations emerging in response to digitalisation and data-driven innovation.

As noted in literature and case studies, digitalisation is reshaping the logic and structure of business models across the agri-food value chain. As digital technologies generate vast amounts of data, ranging from precision agriculture to supply chain monitoring and from consumer behaviour to environmental metrics, the ability to collect, analyze, use and monetize data is becoming a critical source of competitive advantage. The emergence of data-driven business models has shifted value creation from traditional production-based activities to services such as data analytics, predictive insights, traceability, and platform-based coordination. For instance, platform models that connect farmers with service providers, input suppliers, or end consumers (e.g., agritech platforms) exemplify how data can facilitate multisided markets and network effects (Evans & Schmalensee, 2016; Drexl, 2017).

Key dimensions impacted include value proposition (e.g., offering precision agriculture as a service), customer relationships (e.g., real-time advisory services), revenue models (e.g., subscriptions, pay-per-use, or data monetization), and key partnerships (e.g., through data sharing consortia or digital infrastructure providers). New actors, such as data intermediaries, platform operators, and digital ecosystem orchestrators, are increasingly central in food systems, often blurring sectoral boundaries and altering power asymmetries (European Commission, 2020; FAO, 2021). Furthermore, the use of AI, IoT, and blockchain technologies within DE4FS encourages the rise of “data commons” and “data cooperatives” that promote more equitable data governance and shared value creation (Borgman, 2015; Pentland, 2020).

Therefore, digitalisation does not merely augment existing agri-food business models—it transforms them. Understanding and integrating data as a strategic asset requires firms to reconfigure capabilities, rethink value flows, and participate in evolving digital ecosystems. The transition to data-centric and ecosystem-oriented models presents both opportunities and challenges, particularly for SMEs and farmers, who may face digital divides or data ownership issues. Accordingly, fostering inclusive, transparent, and sustainable business models is vital for realizing the full potential of DE4FS.

3.1.3 Societal Readiness Level (SRL) for DE4FS

The third dimension involves the assessment of SRL for DE4FS. SRL is defined here as the extent to which society is prepared to accept and integrate a given innovation (technological or social) into existing practices, norms, and institutions. For current purposes, SRL is conceptualised as a holistic construct encompassing political, environmental, social/ethical, technical, and legal (PESTEL) dimensions. It is understood as a continuum, ranging from the initial recognition of a societal need for developing or implementing a DE4FS, to the widespread societal adoption and utilisation of such systems in response to that need. Assessing SRL provides insight into potential enablers and barriers for societal uptake, and helps identify areas where further engagement or capacity-building may be necessary.

For the analysis, the current SRL of the DE4FS can be assessed using an assessment framework as proposed by Innovation Fund Denmark (2018) (See Appendix II for more examples). In this particular context, SRL is defined here as the degree to which a system is integrated into society in a responsible and inclusive way. Drawing on results from WP3 (case studies) and WP4 (stakeholder engagement), an assessment framework is developed for the analysis with the aim to identify the drivers, barriers, current status, and required actions to advance societal readiness. Table 1 details the stages of the assessment framework and the key dimensions of SRL.

The four dimensions of **SRL; awareness**, **capacity**, **legitimacy**, and **willingness** are adapted from the evolving literature on responsible innovation, science and technology studies, and policy frameworks that extend beyond purely technical readiness (as in TRL: Technology Readiness Levels). These dimensions reflect the broader societal conditions necessary for innovations, especially data-driven ones, to be meaningfully adopted and sustained.

- **Awareness** refers to whether key actors understand the opportunities and risks of a new data-driven initiative.
- **Capacity** involves whether stakeholders, especially marginalized ones, have the resources (skills, infrastructure, institutions) to participate and benefit.
- **Legitimacy** reflects how fair, inclusive, and transparent the governance and value distribution mechanisms are perceived to be.
- **Willingness** captures the motivation and openness of stakeholders to adopt, experiment with, or support change.

Table 1 Assessment framework for Societal Readiness Levels (SRL)

SRL Level	Stage & Description (in DE4FS context)	Awareness	Capacity	Legitimacy	Willingness
SRL 1	**Basic principles observed** – Early recognition of potential for a data-driven food system.	Very limited; confined to technical or academic experts.	Minimal; mostly theoretical or exploratory.	Not yet recognized in formal policy or strategy.	Very low; no stakeholder momentum.
SRL 2	**Concept formulated** – DE4FS concept is articulated; potential use cases are identified.	Awareness begins in niche communities (research, innovation hubs).	Early-stage frameworks or theoretical models exist.	No institutional support; concept remains informal.	Low; a few thought leaders are curious.
SRL 3	**Proof of concept** – Small pilot projects test feasibility of DE4FS components.	Growing in specific sectors (agriculture, tech, policy labs).	Basic tools and data systems exist in isolated pilots.	Informal legitimacy via pilot outcomes and early networks.	Moderate in innovation spaces; still shallow system wide.
SRL 4	**Lab validation** – Models and tools tested in controlled or small-scale real environments.	Broader visibility among key stakeholders (gov't, NGOs, startups).	Prototypes demonstrate usefulness and challenges.	Beginning dialogue with regulators and industry forums.	Higher among early adopters and funders.
SRL 5	**Field validation** – Real-life testing in operational contexts across value chains.	Sectoral awareness and engagement (farmers, processors, etc.).	Infrastructure and governance practices tested in the field.	Emerging alignment with some policy frameworks.	Growing among actors who see tangible value.
SRL 6	**Demonstration in relevant environment** – Multi-actor platforms operate across regions or value chains.	Cross-sector recognition of DE4FS benefits.	Interoperability and governance solutions being demonstrated.	Recognized by leading institutions and regional governments.	Stronger stakeholder coalitions and resource investment.
SRL 7	**System prototypes in operational environment** – Prototype DE4FS systems function across institutional levels.	Public awareness begins; multi-actor dialogue increases.	Technical, legal, and organizational capacity maturing.	Formal engagement with national policy and governance actors.	High among public, private, and civic innovators.
SRL 8	**Qualified system with policy & market uptake** – DE4FS integrated in real markets and public policy (e.g., data sharing standards, value-added services).	Broad societal and institutional awareness.	Institutional models, financing tools, and data standards in place.	DE4FS recognized in national and international policies.	High across value chains, public institutions, and civil society.
SRL 9	**Fully embedded system** – DE4FS is essential to food systems, supporting real-time decision-making, fairness, and resilience.	Universal; data literacy embedded in food system thinking.	Self-sustaining, adaptive infrastructure across scales.	Full legitimacy; backed by law, norms, and trusted governance.	Broad societal, institutional, and individual commitment.

This conceptual framing aligns with methodologies promoted by initiatives such as the Innovation Fund Denmark's SRL Guide, the European Commission's work on responsible research and innovation (RRI), and scholarly work (e.g., Bozeman & Sarewitz, 2011; Stilgoe et al., 2013). It shifts the focus from whether a technology *can* work, to whether it *should* and *will* work in a given societal context. Such a shift is particularly important in theDE4FS, where power asymmetries, data ethics, and farmer inclusion are central challenges.

3.1.4 Mapping drivers and barriers for DE4FS

To deepen the analysis of the drivers and barriers of DE4FS, Table 2 maps key dimensions of the DE4FS to the PESTEL framework. This mapping highlights how political, economic, social, technological, environmental, and legal factors intersect with the evolving ecosystem of data-driven food systems. It supports a structured understanding of the external context in which drivers and barriers emerge and helps to align systemic insights with widely used policy and strategic assessment tools.

Table 2 Mapping of the key dimensions of the DE4FS to the PESTEL framework

PESTEL Dimension	Corresponding DE4FS Dimension	Explanation
Political	Governance & Collaboration	Governance mechanisms, public-private cooperation, policy coordination, and institutional capacity are political enablers. The lack or malfunctioning of such mechanisms may form barriers to the development of the DE4FS.
Economic	Value creation and distribution	Focuses on how economic value is created, shared, and recognized across actors in the DE4FS, including market and non-market transactions. Economic value can be monetary (such as financial returns) and non-monetary (such as health).
Social	Societal alignment	Reflects ethical concerns, inclusiveness, food security and stakeholder trust, key to social license (i.e., informal societal acceptance and trust, beyond legal compliance; depends on perceived legitimacy, fairness, and stakeholder engagement) and engagement.
Technological	Data infrastructure	Supports the whole value chain of data production, exchange and consumption. Pertains to real-time, interoperable and context-sensitive data systems and technological readiness.
Environmental	Scalability & Contextualization	Concerns how localized, place-based data can support environmental sustainability and resilience in food systems.
Legal	Legal & institutional Context	Deals with regulatory clarity, compliance, data rights, and alignment between formal and informal rules.
Cross-cutting	Knowledge & Skills	Though not strictly a PESTEL pillar, skills and capacity-building underpin all domains. This can be seen as a cross-cutting or enabling layer that supports the entire DE4FS system.

Mapping the drivers and barriers to the development of the DE4FS requires a structured and multi-layered analytical approach. By integrating the PESTEL framework with a macro–meso–micro perspective, it becomes possible to systematically identify external and internal factors that shape the uptake, implementation and societal integration of data-driven innovations at various levels. At the macro level, broad systemic forces, such as national digitalisation and data governance policies, global trade dynamics, and climate imperatives, set the overarching conditions for digital transformation. The meso level focuses on organizational structures, such

as agri-business networks, research institutions and food supply chain intermediaries, which mediate the flow of data and innovation between macro policies and grassroots practice. Finally, the micro level considers the behaviours, attitudes and capacities of individual stakeholders, including farmers, consumers and local entrepreneurs, whose participation is essential to building trust and ensuring the equitable deployment of data technologies. When applied together, the PESTEL and macro-meso-micro frameworks offer a comprehensive view of both the enablers and the inhibitors to societal readiness in the food data economy, highlighting critical leverage points for intervention.

3.2 Existing and new business models in the DE4FS

As food systems become increasingly digitalised, data is no longer just a byproduct of agricultural or market activities; it is a central resource around which businesses are reconfiguring their value propositions. Based on a synthesis of existing literature and case studies, four dominant value creation mechanisms can be identified in business models in the data economy as they pertain to food systems:

a) Selling raw data or providing access to data
b) Selling intelligence (providing analysis and insights)
c) Selling data-based products or services
d) Using data for governance purposes

These mechanisms reflect the diverse ways in which data is commodified, analysed and operationalized to generate economic, social and environmental value. To obtain feedback, these four mechanisms were presented to stakeholders in a workshop during the last general assembly of the consortium and the synergy days in 2024[5] (as shown in Figure 2 and Figure 3). The workshop was part of an ongoing effort to evaluate how data-driven innovations are shaping business strategies and stakeholder dynamics in food systems. The stakeholders involved in this assessment include a diverse group of actors engaged in Horizon Europe projects related to digitalisation in the agri-food sector. Specifically, they include companies, EU and national-level policymakers, researchers, and NGOs. Their perspectives reflect both strategic and operational experiences with digital innovation in food systems, and their varying roles may indeed have influenced the responses and outcomes, particularly in terms of priorities, expectations, and perceived challenges.

[5] See more info: https://www.smartagrihubs.eu/synergy-days-2024

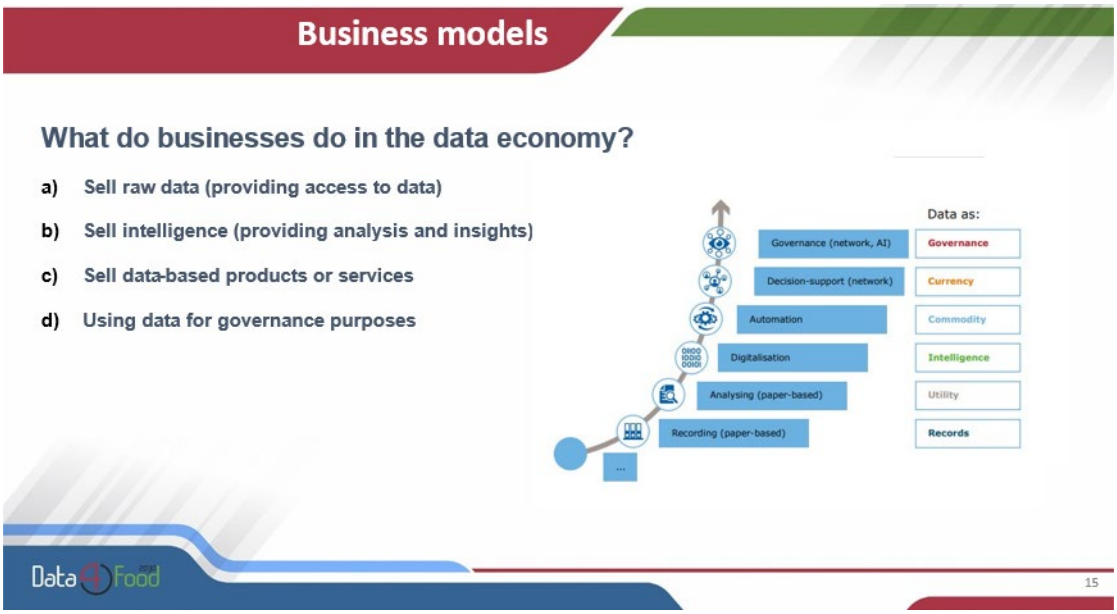

Figure 2 Slide on Business models in the data economy used during the workshop

The responses indicate that selling data-based products and services is likely to emerge as the predominant value creation mechanism in the DE4FS. This reflects a broader trend within agri-food innovation ecosystems, where digital tools such as precision farming platforms, smart irrigation systems, traceability apps, and logistics optimization services are increasingly integrated into commercial offerings (see e.g., Wolfert et al., 2017; Kamilaris et al., 2017; Ciccullo et al., 2022). These products not only embody data but also continuously generate and refine it through user interaction, creating feedback loops that enhance both functionality and profitability. Startups and agritech firms prioritize such models due to their scalability, subscription-based revenue potential and clearer value proposition to end-users such as farmers, processors and retailers.

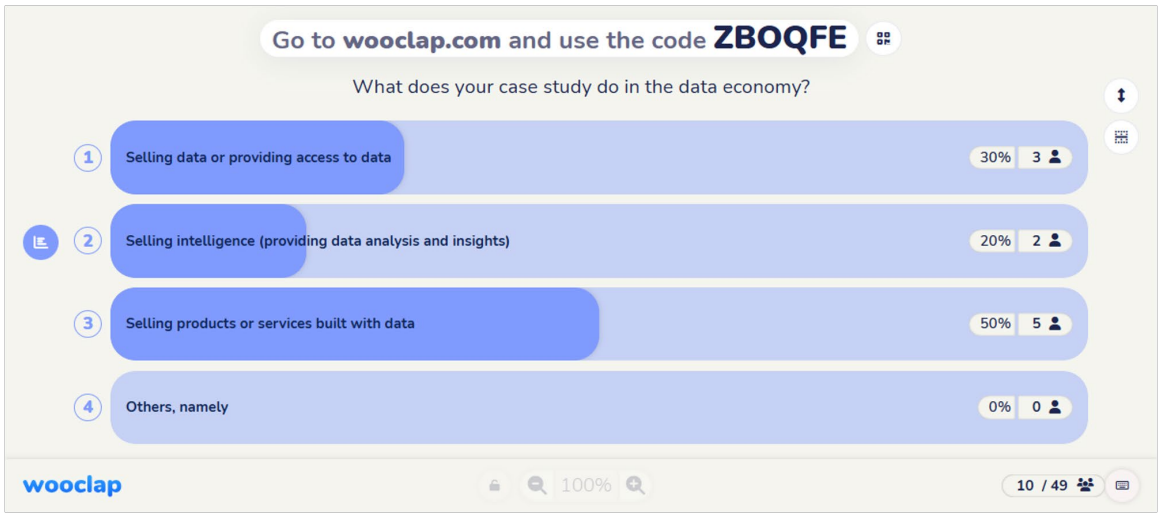

Figure 3 Feedback from case studies on business models in the data economy

While selling intelligence (providing data-driven analysis, insights, and decision-support tools) has received some attention as a business model, it appears to be less prominent than the selling of data-based products. One possible reason is that intelligence services often require a higher degree of trust, customization, and integration into users' decision-making processes, which can

be more complex to deliver and scale. In contrast, data-based products (e.g. dashboards, monitoring tools, digital twins) are often easier to package and market as stand-alone solutions. Additionally, many agri-food stakeholders are still in early stages of digital transformation, focusing first on infrastructure and access to data before investing in more sophisticated value-added services. As the ecosystem matures, the business potential of intelligence-based models may grow, particularly where clear value can be demonstrated.

In contrast, the potential for data-driven governance—including applications in regulatory compliance, certification, public health monitoring, and sustainability assessment—has received relatively limited attention in practice, despite being highlighted in the literature as a transformative opportunity for the sector (Bronson & Knezevic, 2016; Rotz et al., 2019). One possible explanation for this gap is that governance-focused data use often involves complex multi-stakeholder coordination, unclear incentives, or legal and ethical constraints related to data sharing and accountability. Moreover, the benefits of data for governance are frequently diffuse or long-term, making them less attractive from a business model perspective when compared to the immediate monetization potential of commercial products or services.

Nonetheless, scholars have emphasized the critical role of governance-oriented data infrastructures in enabling food system transparency, fostering trust, and meeting societal goals such as environmental sustainability, animal welfare and public health (Fraser, 2021; Eastwood et al., 2019). As such, there remains a significant, yet underutilized opportunity for innovation and policy support to incentivize value creation mechanisms that leverage data for collective and regulatory purposes.

The four mechanisms are discussed below in more detail.

3.2.1 Business models including selling raw data or providing access to data

Some companies focus on harvesting and commodifying raw agricultural data. For instance, farm management platforms and precision farming tools collect geospatial, meteorological, and agronomic data from farmers and their equipment. These datasets are often sold or shared with third-party actors, such as insurance firms, input suppliers, or public agencies. However, as Bronson & Knezevic (2016) argue, farmers often lose control over these data, raising concerns about ownership, privacy, and asymmetrical power relations in agri-data markets.

Business models in data sharing initiatives aim to create and capture value through secure, interoperable data exchange frameworks, yet they face significant monetization challenges. According to Moonen et al. (2025), models such as subscriptions, licensing, freemium, and sponsorships are common, but their effectiveness varies depending on the technological and governance structures in place. Federated data spaces, for instance, struggle with usage-based pricing due to the lack of centralized data visibility, whereas centralized platforms more easily monetize through direct services and network effects. The report highlights that only 15% of European data spaces currently have a clear revenue model, emphasizing the need for hybrid approaches and investment-driven strategies to achieve sustainability. Ultimately, aligning governance, technology, and user-centric design is essential for scalable, revenue-generating data ecosystems.

3.2.2 Business models involving selling intelligence

Many agri-tech firms offer value through proprietary algorithms and analytics. They process raw data to deliver tailored recommendations on seeding rates, fertilization timing, or disease management to optimize productivity. These services are typically offered through subscription-based business models. As Bronson (2019) shows, this model can deepen digital divides: large farms are often better positioned to integrate such technologies, while smaller or more traditional producers are left behind. At the same time, these tools often prioritize yield efficiency over broader sustainability or social outcomes.

3.2.3 Business models involving selling data-based products or services

Companies are also embedding data into physical and digital products that promise value-added functions. This includes autonomous machinery, blockchain-based traceability platforms, or carbon credit certification systems based on sensor-verified practices. Bianchi & Penker (2023) explore how such services underpin emerging “data economies” that aim to align food system sustainability with economic incentives. However, as Birch (2022) highlights, this often reflects a broader shift toward “rentiership” in “technoscientific capitalism” where control over data infrastructure becomes a source of profit, regardless of actual productivity gains.

3.2.4 Business models involving using data for governance purposes

In some cases, data is not sold per se, but used internally or collaboratively for governance. Retailers and food processors, for example, use supply chain data to enforce sustainability standards, manage reputational risk, or comply with ESG frameworks. The I4DATA project in Spain offers an excellent example: By linking data on tourism-related circularity practices to the evolving regulatory landscape of the Balearic Islands, the project enabled policymakers to tailor incentives for more sustainable business models. Meanwhile, farmers and cooperatives may use data to engage in self-governance or collective bargaining. However, as Rotz et al. (2019) and Milan & Treré (2019) show, the consolidation of data infrastructure can marginalize alternative voices and exacerbate systemic inequalities, especially when data governance is dictated by corporate actors or shaped by dominant knowledge systems rooted in the Global North. These so-called “northern epistemologies” refer not to specific countries in the Global North, but to broader ways of knowing and governing that prioritize standardised, technocratic, and market-driven approaches. Such frameworks often overlook or undervalue local, experiential, or indigenous knowledge systems, particularly those from the Global South or from marginalized communities. As a result, data practices risk reinforcing existing power asymmetries unless more inclusive governance models are adopted.

It should be noted that the use of data to optimise operational processes in the food systems is an important application and is implicitly covered within the identified mechanisms, predominantly under (c) selling data-based products or services and (d) using data for governance purposes. For instance, when businesses deploy data-driven tools to enhance productivity, logistics, or resource efficiency, this often falls under mechanism (c). Meanwhile, internal data use for coordinating supply chains, ensuring compliance, or managing performance aligns with

mechanism (d). While not a standalone category, operational optimisation represents a cross-cutting function that supports and is enabled by these broader data-driven models.

3.3 Assessment of the SRL

This chapter presents findings concerning the current SRL of the DE4FS, identifying key barriers, enablers, and actionable strategies. Often overshadowed by the technological readiness level (TRL), the SRL for adopting data-driven innovations in European food systems is a critical determinant of successful digital transformation. Drawing from insights obtained in case studies and stakeholder dialogues, this assessment evaluates stakeholder engagement, inclusivity, trust and governance as key SRL indicators. At macro level, EU strategies and regulations relevant to DE4FS can support or hinder the development and societal embedding of data-driven innovations in the agri-food domain. As such, they are relevant to the assessment of the SRL. The case studies represent micro- and meso-economic implementations across food production, supply chains, and circular economies.

3.3.1 EU strategies and regulations relevant to the SRL of DE4FS

The first focus is on the relevant European strategies and legislative instruments that influence the development and SRL of DE4FS. This includes strategic initiatives such as the European Strategy for Data, the Digital Europe Programme, and the development of Common European Data Spaces. The analysis also considers regulatory instruments such as the General Data Protection Regulation (GDPR), the Data Act, and the Artificial Intelligence (AI) Act. Special attention is given to how these strategies and regulations address issues of data ownership, access, and governance, particularly in relation to both personal and non-personal data. These legal and strategic developments provide the broader institutional context within which DE4FS must operate.

In addition to digital strategies and regulations, general policy frameworks such as the EU Food 2030 strategy (particularly the ‘data and digital transformation’ pathway for action to transform food systems) and General Food Law Regulation (EC No 178/2002) also contain elements relevant to the societal embedding of data-driven approaches. These frameworks highlight priorities such as sustainability, transparency, and trust in food systems. These are dimensions that intersect with data governance and influence the perceived legitimacy and societal acceptance of DE4FS innovations. Taken together, these digital and sectoral policies shape both the opportunities and constraints for advancing the societal readiness of data-driven food systems across Europe.

Table 3 presents an assessment of key EU regulations and strategies based on the SRL dimensions Awareness, Capacity, Legitimacy, and Willingness, as they relate to the development of a DE4FS, drawing on expert judgement and document analysis. The table highlights how these policy instruments support or limit progress across different SRL aspects, offering insight into their role in enabling the societal embedding of data-driven innovation in the agri-food sector.

Table 3 Assessment of EU Regulations and Strategies by Societal Readiness Level (SRL) Dimensions for the Data Economy in Food Systems (DE4FS)

EU Regulation / Strategy/Initiative	Awareness	Capacity	Legitimacy	Willingness
Data Act (2023/2854)	✅	✅	✅	✅
Integrated Farm Statistics (2018/1091)	✅	◑	✅	◑
Farm Sustainability Data Network (2023/2674)	✅	✅	✅	✅
Novel Food Regulation (2015/2283)	✅	◑	✅	◑
Data Governance Act (2022/868)	✅	✅	✅	✅
Database Directive (96/9/EC)	◑	◑	◑	◑
Treaty on the Functioning of the EU	✅	❌	◑	◑
General Food Regulation (178/2002)	✅	◑	✅	✅
GDPR (2016/679)	✅	✅	✅	✅
Digital Fairness Act (forthcoming)	✅	◑	✅	✅
Digital Services Act (DSA)	✅	✅	✅	✅
AI Act (2024/1689)	✅	✅	✅	✅
Digital Europe Programme (2021/694)	✅	✅	✅	✅
Horizon Europe (2021/695)	✅	✅	✅	✅
CAP Strategic Plans (2021/2115)	✅	✅	✅	✅
EU Strategy for Data	✅	✅	✅	✅
Data Union	✅	✅	✅	✅
Nature Restoration Law (2024/1991)	✅	◑	✅	✅

Legend:

- ✅ = Strong contribution
- ◑ = Moderate/Partial contribution
- ❌ = Weak/Absent contribution

3.3.2 Current SRLs and challenges in societal readiness

The transition toward a data-driven food system holds the potential to improve efficiency, sustainability and resilience across the agri-food value chain. However, societal readiness - the extent to which various stakeholders are prepared and able to engage with this transformation - remains uneven across the food supply chain (or agri-food system) and still faces significant challenges. During the monthly meeting on July 6, 2025, the case study leaders were asked to assess the current SRLs for seven stakeholder groups. As shown in Figure 4, across stakeholder groups in the nine case studies in the project Data4Food2030, a varied landscape of societal readiness emerges.

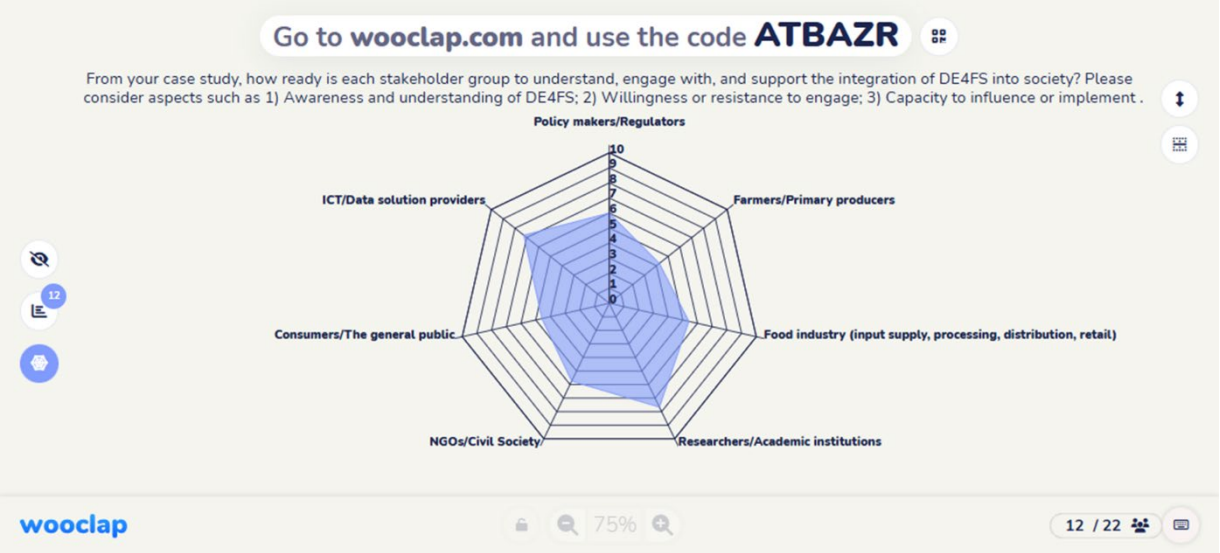

Figure 4 Assessment of current SRLs for different stakeholder groups by case studies

Researchers and academic institutions exhibit the highest average readiness (7.7), reflecting high levels of engagement, understanding, and capacity to support DE4FS integration. ICT and data solution providers follow closely (7.3), with a majority of responses concentrated in the higher SRL bands, indicating strong technical capacity and alignment with digital transformation goals. Policy makers and regulators score moderately high (6.0), with most responses indicating moderate to high awareness and willingness but possibly limited by institutional inertia or uneven policy implementation.

In contrast, farmers and primary producers (4.3) and consumers (4.6) show lower readiness, suggesting gaps in awareness, relevance, or access to supportive infrastructure and decision-making processes. The food industry presents a mid-range score (5.4), reflecting partial integration and varying engagement across subsectors. NGOs and civil society (5.8) demonstrate a moderate but diverse level of readiness, with responses spread across the scale, likely influenced by the heterogeneity of their roles and proximity to digital policy debates.

Overall, the results underscore the need for targeted engagement and capacity-building, particularly for those stakeholders further removed from data governance structures or technical expertise.

The following challenges have been identified from case studies and stakeholder dialogues.

Trust deficit

In the Premium Grain Chain, resistance to data sharing emerged from farmers fearing exploitative commercial use. Solutions included co-designed data licenses ensuring revenue-sharing. PIGLINK revealed distrust in interoperability tools, necessitating transparent data-usage protocols to gain farmer buy-in.

Inclusivity gaps in data access

The case THESIS highlighted exclusion of remote producers from sustainability-data platforms due to connectivity issues. Mitigation involved low-tech data-collection alternatives (e.g., SMS-based reporting). The case AMAFLOW identified gender disparities in waste-data contributions, prompting gender-targeted digital literacy programs.

Governance fragmentation
The case TEUDS exposed inconsistent data standards across regions, slowing policy implementation. The case advocated for EU-wide governance frameworks. The case Zero FLW demonstrated that centralized FLW (food loss/waste) monitoring requires municipal-level data-sharing agreements to function effectively.

3.3.3 Improving SRL for DE4FS

Achieving higher SRLs often hinges on the ability to foster genuine co-creation among diverse stakeholders. For instance, the DIRECT project in Germany exemplifies how multi-actor collaboration can elevate SRL by embedding shared values and responsibilities into data system design. In this case, retailers, farmers, and logistics providers co-developed a real-time freshness monitoring system for perishable goods. By aligning data flows with each actor's needs and contributions, the system not only improved operational efficiency but also ensured a more equitable distribution of value across the supply chain. This kind of collaborative architecture builds trust, enhances data relevance and promotes mutual accountability; key characteristics of higher SRL stages (SRL7-SRL9).

Similarly, higher SRL can be achieved through policy-science integration, where regulatory frameworks actively incorporate and respond to data innovations. The I4DATA project in Spain offers a compelling example. By linking data on tourism-related circularity practices, such as waste generation, water use, and resource recovery, to the evolving regulatory landscape of the Balearic Islands, the project enabled policymakers to tailor incentives for more sustainable business models. This feedback loop between real-world data and environmental regulation accelerated both policy responsiveness and stakeholder adoption, a hallmark of advanced societal readiness. Such integration illustrates the critical role of governance in bridging technological potential with public value outcomes.

3.4 Mapping drivers and barriers

3.4.1 Drivers and barriers at macro level

At the macro level, policy and regulatory frameworks stand out as the principal sources shaping the drivers and barriers to new models of business and governance processes in the DE4FS (see Appendix II for the list of EU regulations and strategies and their relevance to the DE4FS).

The EU's comprehensive suite of strategies and regulations provides critical enablers such as harmonized data collection (Regulation 2018/1091), trust-building mechanisms for secure data sharing (Data Governance Act 2022/868) and funding programs supporting digital innovation (CAP Strategic Plans 2021/2115, Horizon Europe 2021/695). These initiatives promote standardization, interoperability and digital infrastructure development, thereby driving the digital transformation of agri-food sectors. Conversely, the same regulatory landscape also introduces significant challenges. Complex legal and technical requirements, as seen in GDPR (2016/679) and the Data Act (2023/2854), create high compliance costs, ownership disputes and barriers to participation for smaller actors. Fragmented implementation of policies across member states, slow data update cycles and gaps in regulation coverage (e.g., limited explicit treatment of data flows in foundational EU treaties) further complicate the operationalization of data-driven business models. This dual role of policy - as both catalyst and constraint - is pivotal to understanding the

evolution of data ecosystems in agriculture and food systems, underscoring the need for harmonized, flexible regulatory approaches that balance innovation with protection.

Table 4 summarises the main macro-level drivers and barriers shaping DE4FS, illustrating how political, economic, social, technological, environmental and legal factors interact with relevant EU strategies and regulations. However, the impact of these factors is strongly influenced by context, including regional policies, sector-specific traits and stakeholder capacities. For instance, while EU-wide regulations like GDPR and the Data Governance Act provide a common legal framework, their implementation varies across countries due to differences in infrastructure and administrative ability. Likewise, funding programs may boost innovation in well-resourced regions but have limited effect in remote or less developed areas. Social factors such as digital literacy and cultural attitudes toward data sharing also differ, influencing adoption rates of new business models. Technological and environmental challenges similarly vary depending on agricultural systems and sustainability goals. Thus, understanding the local, sectoral, and institutional context is essential to tailor strategies effectively and unlock the full potential of data-driven innovation in the agri-food sector.

Table 4 Drivers and barriers at macro level (EU regulations and strategies)

PESTEL Dimension	Drivers	Barriers	Examples of Relevant EU Regulations / Strategies
Political	- EU-wide digital strategies supporting data ecosystems	- Regulatory complexity across sectors	- EU Strategy for Data (Common European Data Spaces)
	- Policy frameworks encouraging data sharing and innovation	- Uneven policy implementation across member states	- CAP Strategic Plans (2021/2115)
Economic	- Funding programs accelerating digital innovation	- High costs of digitalisation for small actors	- CAP Strategic Plans (2021/2115)
	- Market opportunities through data monetization and traceability	- Unclear ROI on data investments	- Horizon Europe (2021/695)
		- Market competition risks for smaller producers	- Digital Europe Programme (2021/694)
Social	- Growing consumer demand for transparency and sustainability	- Resistance to change and limited digital literacy	- Data Governance Act (2022/868)
	- Multi-actor collaboration and data cooperatives	- Unequal access to technology in rural areas	- Digital Europe Programme (2021/694)
Technological	- Advances in IoT, AI, cloud platforms enabling smart farming	- Lack of interoperability standards	- Data Act (2023/2854)
	- Standardization efforts improving interoperability	- Legacy infrastructure constraints	- AI Act (2024/1689)
		- Technical complexity of data infrastructures	- EU Strategy for Data
Environmental	- Policy focus on sustainability and ecosystem restoration driving data needs	- Environmental costs of digital infrastructure (energy use)	- Nature Restoration Law (2024/1991)
	- Demand for carbon tracking and environmental footprint reduction	- Integration challenges for diverse environmental data	- Farm Sustainability Data Network (2023/2674)
Legal	- Data protection laws build trust in data handling	- Strict compliance burdens (e.g., GDPR)	- GDPR (2016/679)
	- Legal frameworks enabling data access rights	- Ownership disputes and unclear data rights	- Data Governance Act (2022/868)
		- Slow updates and complex consent mechanisms	- Database Directive (96/9/EC)
			- Data Act (2023/2854)

3.4.2 Drivers and barriers at meso-micro level

At the meso-micro level, the study explored the key drivers and barriers influencing the adoption and development of new business models within the DE4FS following the PESTEL framework. Drawing from literature and building on qualitative data collected from various case studies and stakeholder interviews, this section synthesises diverse perspectives to identify the critical factors that either facilitate or hinder innovation and transformation in this domain. Figure 5 shows the distribution of the responses during the workshop in Barcelona with representatives from the case studies.

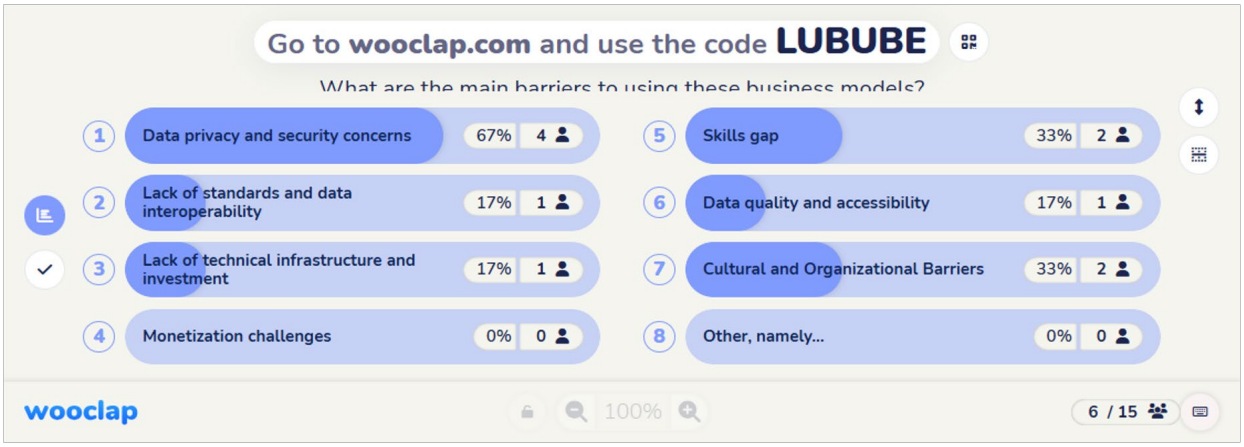

Figure 5 Feedback from case studies on main barriers in using the new business models in the DE4FS

Among the barriers identified by stakeholders in developing new business models within the DE4FS, concerns around data privacy and security emerged as the most significant. These issues create hesitation and mistrust, limiting data sharing and collaboration, which are essential for innovative business practices. In addition, a pronounced skills gap poses a challenge, with many organizations lacking the expertise necessary to effectively manage and leverage data assets. The absence of widely accepted standards and issues with data interoperability further complicates integration efforts, impeding seamless data exchange across platforms and sectors. Beyond technical hurdles, cultural and organizational barriers also play a critical role, as entrenched mindsets and resistance to change can slow down adoption of novel business models, hindering agility and innovation in the evolving data landscape.

The drivers for and barriers to new business models in the data economy are multifaceted, as highlighted by stakeholder responses and enriched by detailed case studies within the project. Table 5 summarises key drivers and barriers across PESTEL dimensions, illustrating the complex landscape that organisations must navigate. Politically, while policy support such as the EU's digital compasses and government subsidies for public-private data partnerships serve as important driver, regulatory complexity and concerns around GDPR and data sovereignty pose significant barriers, as seen in cases like PGC and AMAFLOW. Economically, new business models leveraging traceability and circular economy principles offer value creation opportunities; however, high digitalisation costs, unclear returns on investment, and fierce market competition particularly challenge small actors (cases I4Data & ISDaaS). Social barriers, including resistance to change and limited digital literacy, especially among farmers, contrast with drivers like growing

consumer demand for transparency and multi-actor collaboration (Zero FLW, THESIS). Technological barriers such as lack of interoperability standards, legacy system constraints, and technical infrastructure complexity are prominent obstacles despite advances in IoT, AI, and cloud platforms demonstrated in the case study PIGLink and DIRECT. Environmental considerations also influence business models, with sustainability needs driving innovation while the environmental costs of digital infrastructure raise concerns (PGC and I4Data). Finally, legal challenges arise from strict regulatory frameworks and complex consent requirements, which restrict scalability and flexibility, even as initiatives like the Sitra model[6] aim to facilitate trusted data exchange (TEUDS & AMAFLOW). Collectively, these insights underscore the necessity of addressing diverse barriers in tandem to unlock the full potential of data-driven business models in DE4FS.

Table 5 Drivers and barriers identified in case studies

PESTEL	Drivers	Barriers	Case Studies
Political	- EU/national digital compasses and policy support for developments in data spaces	- Regulatory complexity across sectors	PGC, TEUDS Zero FLW, AMAFLOW
	- Government subsidies for public-private data partnerships	- GDPR compliance efforts and data sovereignty concerns	
Economic	- New business models (e.g., value creation through traceability, circular economy)	- High costs of digitalisation for small actors	PGC I4Data ISDaaS AMAFLOW
	- Data monetization potential	- Unclear ROI for data tools	
	- Funding programs	- Market competition threatening small producers	
Social	- Multi-actor collaboration	- Resistance to change	Zero FLW THESIS ISDaaS
	- Consumer demand for transparency	- Limited digital literacy among farmers	
	- Inclusive and fair data access and fairness focus	- Uneven access to technology across regions	
	- Required application of FAIR principles		
Techno-logical	- Availability of IoT devices and cloud platforms	- Lack of interoperability standards	PIGLink TEUDS DIRECT THESIS
	- Innovation in AI and ML for food waste reduction and sustainability	- Legacy system limitations	
		- Technical complexity in infrastructure setups	

[6] The Sitra rulebook model for a fair data economy is a guide for creators of fair data economy data spaces. Agreement templates and other tools make it easier to build and join new data spaces, which highlight transparency in data sharing. See more information at: https://www.sitra.fi/en/publications/rulebook-for-a-fair-data-economy/

Environ-mental	- Need for sustainability and reduction of environmental footprint	- Environmental costs of digital infrastructure (e.g., servers)	PGC AMAFLOW THESIS I4Data
	- Carbon tracking and food waste valorisation		
Legal	- Regulatory alignment (CSRD, CSDDD) requires digital tools and data to support compliance.	- Strict and inflexible legal frameworks (esp. for scaling data reuse)	THESIS PGC PIGLink TEUDS AMAFLOW
	- Development of rulebooks (e.g., Sitra model) to facilitate trusted data exchange	- Complex consent and user agreements	
		- Regulatory uncertainty about sustainability reporting and consumer communication. EU delayed implementation of key sustainability directives CSRD, CSDDD, Green Claim.	

4 Discussion

The analysis of drivers and barriers in DE4FS reveals a landscape with complex, potentially conflicting interests, and deeply embedded in social, political, and economic contexts. Rather than presenting a neutral or technical progression, the transition toward a more data-driven food system raises fundamental questions about power, values, inclusion and control.

Against this backdrop, several cross-cutting issues emerged as particularly salient in shaping how drivers and barriers play out in practice. These issues are not just technical challenges, but reflect deeper questions about values, governance, and the uneven distribution of risks and opportunities across food systems. The following discussion highlights five themes that stood out during the analysis as especially relevant for understanding the dynamics of the DE4FS. Each theme sheds light on how data-driven transitions are embedded in wider societal, institutional and political contexts.

4.1 Competing claims and values in food systems

Food systems are shaped by multiple, often competing claims and values, such as economic efficiency and productivity, environmental sustainability, cultural food traditions, and public health. The emerging data economy can act as a disruptive force, with the potential to either support or undermine these values. For instance, while data-driven tools may enhance resource efficiency or traceability, they may also reinforce certain production models over others, or overlook less quantifiable values such as cultural heritage, smallholder autonomy, or animal welfare. As a result, the drivers and barriers associated with the DE4FS cannot be interpreted in purely technical terms but must, rather, be understood as embedded within broader normative debates about what food systems are for, and for whom they are.

4.2 The political economy of data

The DE4FS is not only a site of innovation but also a domain of negotiation and contestation, where divergent interests and value frameworks intersect. The political economy of data - who owns it, who controls access, who benefits from its use - shapes the opportunities and constraints that actors face. Many barriers identified in this report, such as trust deficits, lack of equitable benefit-sharing, or regulatory fragmentation, stem from unresolved issues about data governance and power asymmetries. The increasing role of platform companies, for instance, raises questions about market concentration and dependency, while public institutions face the challenge of creating legal and infrastructural safeguards that protect both innovation and rights. Understanding drivers and barriers thus requires attention to institutional arrangements, economic interests, and the political dynamics behind data flows.

Rather than operating in a vacuum, the data economy is embedded within institutional structures, driven by economic interests, and marked by asymmetries in access and control. (Birch, 2022; Srnicek, 2016). In the DE4FS, questions of ownership, access, and benefit-sharing are core issues. Private platform providers may set the terms for data flows, while farmers and smaller actors may lack the bargaining power or legal protections to negotiate fair data use. Public institutions are increasingly tasked with building trustworthy and inclusive governance arrangements that protect data sovereignty and prevent exploitative dynamics (FAO & ITU, 2022).

4.3 The multifaceted nature of the DE4FS

As shown in earlier sections, the DE4FS comprises diverse and overlapping sub-ecosystems that evolve in response to sectoral demands, regulatory landscapes, and societal expectations. Such diversity poses challenges to the standardisation of drivers and barriers across varying contexts. What works as a catalyst in one domain may be irrelevant - or even detrimental - in another. For example, high interoperability may benefit value chain actors but overwhelm smaller producers lacking technical capacity. Similarly, actors operate with different understandings of value: for a technology provider, value may lie in scaling solutions whereas for a farmer, it may lie in better margins or autonomy. As such, the DE4FS does not lend itself to a one-size-fits-all analytical framework. A comprehensive and integrative perspective is therefore necessary to capture the full complexity of data economy transitions in food systems.

4.4 Context dependence and stakeholder perspectives

Drivers and barriers are deeply context-dependent. They vary across regions, sectors, regulatory environments, and stakeholder positions. A regulatory standard may be seen as an enabler by civil society (for increasing transparency) but as a barrier by smaller producers (due to compliance costs). A digital tool might enhance data use for one group while raising ethical or surveillance concerns for another. As such, stakeholder engagement is not only a methodological necessity but also essential for understanding the dynamics of system transitions: it reveals the pluralism of experiences and the contested nature of change. A robust understanding of drivers and barriers must, therefore, include space for negotiation and dissent.

4.5 Inclusiveness and the right to opt out

Inclusiveness is often positioned as a normative goal in the development of digital food systems. However, genuine inclusiveness must also account for the right to opt out. Participation should not be coerced or assumed, particularly in systems where data asymmetries and trust deficits persist. Respecting the agency of those who choose not to engage - or to engage only partially - with digital infrastructures is a crucial aspect of ethical system design. This also invites a rethinking of what "success" means in DE4FS initiatives: rather than measuring only uptake or scalability, attention must also be paid to autonomy, informed consent, and the protection of alternative practices and knowledge systems.

4.6 Toward reflexive governance

Taken together, these insights point to the need for a reflexive governance of the DE4FS; one that recognises plurality, contextuality and evolving dynamics. This means not only enabling data-driven innovation but also critically assessing its assumptions, beneficiaries, and unintended effects. It requires ongoing dialogue among stakeholders, adaptive policy instruments, and ethical frameworks that go beyond compliance. In short, the future of the DE4FS is not only a technical matter but also a social and political project that demands deliberation, transparency, and care.

5 Conclusion and next steps

The transition to a DE4FS represents a multi-layered transformation involving not just digital tools but also new ways of organizing knowledge, value and governance. This deliverable has mapped the drivers and barriers influencing the development of the DE4FS at different levels and through different lenses, highlighting the diversity of stakeholder experiences and the contextual nature of change. As the digitalisation of food systems accelerates, the following concluding reflections outline next steps in three key areas: EU strategies and regulations, business models and SRL.

5.1 On EU strategies and regulations

The European Union plays a central role in shaping the enabling environment for the DE4FS. Existing strategies, including the European Data Strategy, the Farm to Fork Strategy, the Digital Services Act and the Data Act, signal the EU's ambition to create a harmonised, fair, and sustainable data ecosystem. However, the case studies and barriers analyses suggest that while regulations provide necessary safeguards, they may also generate uncertainty or uneven implementation, particularly for small-scale and public-sector actors.

Going forward, EU strategies must more clearly articulate how general-purpose data regulations (like GDPR and the Data Act) apply in food system contexts. Clarifying data ownership, interoperability standards, and public data infrastructures for agriculture will be essential. Moreover, alignment between sustainability objectives and digital innovation policy remains incomplete. Bridging this gap requires continued co-creation of regulatory frameworks in dialogue with stakeholders across the value chain, including civil society.

In addition to clarifying and aligning regulatory objectives, attention must also be given to the implementation and monitoring of EU strategies across Member States and sectors. Ensuring that data regulations remain adaptable to specific societal needs, such as those in food systems, requires iterative, inclusive governance mechanisms. This includes regular evaluation of how regulations function in practice, as well as institutional capacity to revise or refine approaches based on feedback from diverse stakeholders. Building such reflexive capacity into the policy cycle is essential for supporting both innovation and social legitimacy.

5.2 On Business models

The rise of the DE4FS challenges existing business models while opening new opportunities for value co-creation. Current models often rely on data extraction or platform centralisation, raising concerns about data monopolies and limited benefits for primary producers. The case studies illustrate that inclusive and circular data business models - those that fairly reward data sharing and support data commons - are still emergent but crucial.

Future business models must go beyond monetisation to incorporate values such as trust, reciprocity and transparency. This includes cooperative data platforms, service-based models tailored to specific sectors, and models that embed ethical and social returns into value propositions. Public and private support for experimentation with alternative data business models will be key, especially in linking data-driven services with agroecological, localised, or fair-trade initiatives.

5.3 On SRL

SRL is a highly context-dependent and relational concept. Trust and inclusivity emerge as pivotal factors: many stakeholders remain sceptical about data use, ownership, and fairness, especially where benefits are unclear or past experiences have eroded trust. This suggests that high technical capacity does not necessarily correlate with high readiness. Successful transition to the DE4FS requires abandoning one-size-fits-all approaches in favour of adaptive governance, localized co-creation, and policy-science integration.

Tools that measure SRL in quantitative and qualitative terms, such as indices tracking longitudinal trust, perceived benefit-sharing, and data-equity metrics, should be developed and tested. These can support policymakers and practitioners in assessing where interventions are most needed and which kinds of support will be most effective.

In summary, building a fair, inclusive and innovative DE4FS calls for a shift from isolated digital solutions to systemic and participatory innovation. Continued engagement with diverse actors, reflexive governance mechanisms, and alignment between policy goals and implementation realities will be essential in moving from vision to practice.

6 Literature and websites

Declaration of generative AI and AI-assisted technologies in the writing process
During the preparation of this work the author(s) used ChatGPT to improve language and readability and Perplexity for the literature review. After using these tools/services, the author(s) reviewed and edited the content as needed and take full responsibility for the content of the publication.

Bhatti, H.J.; Danilovic, M.; Nåbo, A. A Multidimensional Readiness Index for the Electrification of the Transportation System in China, Norway, and Sweden. *Future Transp.* **2023**, *3*, 1360-1384. https://doi.org/10.3390/futuretransp3040075

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Annex I: List of EU regulations and strategies relevant to DE4FS

EU Strategies and regulation (including initiative)	Description / Scope	Relevance to DE4FS
Regulation (EU) 2018/1091 – Integrated Farm Statistics (IFS)	Harmonised data collection on farm structures, incl. ICT module	Provides periodic data on digital adoption in agriculture
Regulation (EU) 2022/868 – Data Governance Act (DGA)	Enables secure and trustworthy data sharing via intermediaries	Facilitates voluntary farm data sharing
Regulation (EU) 2023/2854 – Data Act	Establishes rights to access and use IoT-generated data	Enables farmers to control and use machinery data
Regulation (EU) 2016/679 – General Data Protection Regulation (GDPR)	Regulation on the protection of personal data	Applies to FMIS and farm-level data with personal identifiers also relates to food, for example consumers wanting to collect data on their food purchases from a place like Albert Heijn can do so through an Article 15 GDPR request. Also helps clarify the roles of conduct of conducts
Regulation (EU) 2021/2115 – CAP Strategic Plans	CAP funding for digitalisation and innovation	Funds smart farming tools, advisory systems, FaST
Regulation (EU) 2021/694 – Digital Europe Programme	Supports digital infrastructure and innovation hubs	Funds EDIHs supporting agri-food digitalisation
Regulation (EU) 2021/695 – Horizon Europe	EU R&I funding programme	Funds research on data-driven food systems
EU Strategy for Data (non-binding)	Policy framework for Common European Data Spaces	Lays foundation for Agriculture Data Space
Data Union (new strategy of European commission)	new data strategy focusing of leveraging AI	

Digital Markets Act (DMA)	The Digital Markets Act is an EU regulation that aims to make the digital economy fairer and more contestable	
Digital Services Act (DSA)	Addresses illegal content, transparent advertising and disinformation.	Impacts agri-digital platforms and advisory tools
AI Act 2024/1689	Rules for safe and ethical AI use	Covers predictive and automated AI tools in farming
Digital Fairness Act (forthcoming)	Addresses digital fairness including dark patterns, personalization, contracts, and influencer marketing.	Ensures ethical use of digital interfaces in food-related platforms (e.g. digital marketplaces, food delivery apps), especially relevant where consumer data is used for targeted pricing, nudging, or behavioural manipulation in food choices or agricultural input sales.
Nature Restoration Law (2024/1991)	Sets targets for restoration of degraded ecosystems, including agricultural land.	Requires integrated land-use and biodiversity data. Creates demand for data-driven agri-environmental monitoring, and highlights the need for transparent, interoperable data flows between agricultural systems and ecological databases.
General Food Regulation (EC) No 178/2002	Established the European Food Safety Authority (EFSA) and general principles of food law.	Provides a foundation for food data governance in safety and traceability. Relevant for data-sharing between producers, authorities, and consumers to ensure transparency and rapid response in the digital food supply chain.
Novel Food Regulation (2015/2283)	Defines categories and approval processes for novel foods, including those from new technologies.	Directly linked to emerging data types (e.g. genomics, fermentation process data) in food innovation. Supports the use of digital tools for risk assessment, traceability, and consumer communication about novel food products.

Treaty on the Functioning of the European Union	Establishes the internal market enabling free movement of goods, services, capital, and people, but not explicitly data.	Critical in framing discussions on data sovereignty in food systems. Absence of "data" in the treaty creates uncertainty around cross-border agri-data flows, with implications for supply chain digitalisation and data-sharing agreements.
Database Directive (96/9/EC)	Grants copyright-like protection to creators of databases.	Impacts the ownership, control, and re-use of agricultural and food system data repositories. Raises questions about data access and value distribution, especially for platforms aggregating farm-level or consumer data.
Regulation 2023/2674 (Farm Sustainability Data Network)	Expands the Farm Accountancy Data Network (FADN) into a broader sustainability data collection system (FSDN).	A cornerstone for a public data infrastructure in agriculture. Enables standardized, structured data on farm sustainability, crucial for benchmarking, policymaking, and fair participation in the agri-data economy. Promotes open data principles and interoperability.

Annex II: Societal Readiness Levels defined in the literature

SRLs as defined by Denmark Innovation Fund

SRL 1 – identifying problem and identifying societal readiness
SRL 2 – formulation of problem, proposed solution(s) and potential impact, expected societal readiness; identifying relevant stakeholders for the project.
SRL 3 – initial testing of proposed solution(s) together with relevant stakeholders
SRL 4 – problem validated through pilot testing in relevant environment to substantiate proposed impact and societal readiness
SRL 5 – proposed solution(s) validated, now by relevant stakeholders in the area
SRL 6 – solution(s) demonstrated in relevant environment and in co-operation with relevant stakeholders to gain initial feedback on potential impact
SRL 7 – refinement of project and/or solution and, if needed, retesting in relevant environment with relevant stakeholders
SRL 8 – proposed solution(s) as well as a plan for societal adaptation complete and qualified
SRL 9 – actual project solution(s) proven in relevant environment

Stages SRL 1-3 reflect the early work in a research project, including suggesting and testing on a preliminary basis a technical and/or social solution to a technical or a societal problem. Here reflections about the general societal readiness towards the idea and its proposed solution(s) are required, including identifying relevant stakeholders and how to include them (such as end users, the right communities, etc.).

Stages SRL 4-6 represent the actual solution(s), the research hypothesis, and testing it/them in the relevant context in co-operation with relevant stakeholders, while keeping a focus on impact and society's readiness for the product. In these stages expectations on the societal adaptation must be described in specific terms and, to the extent possible, be part of the test phase.

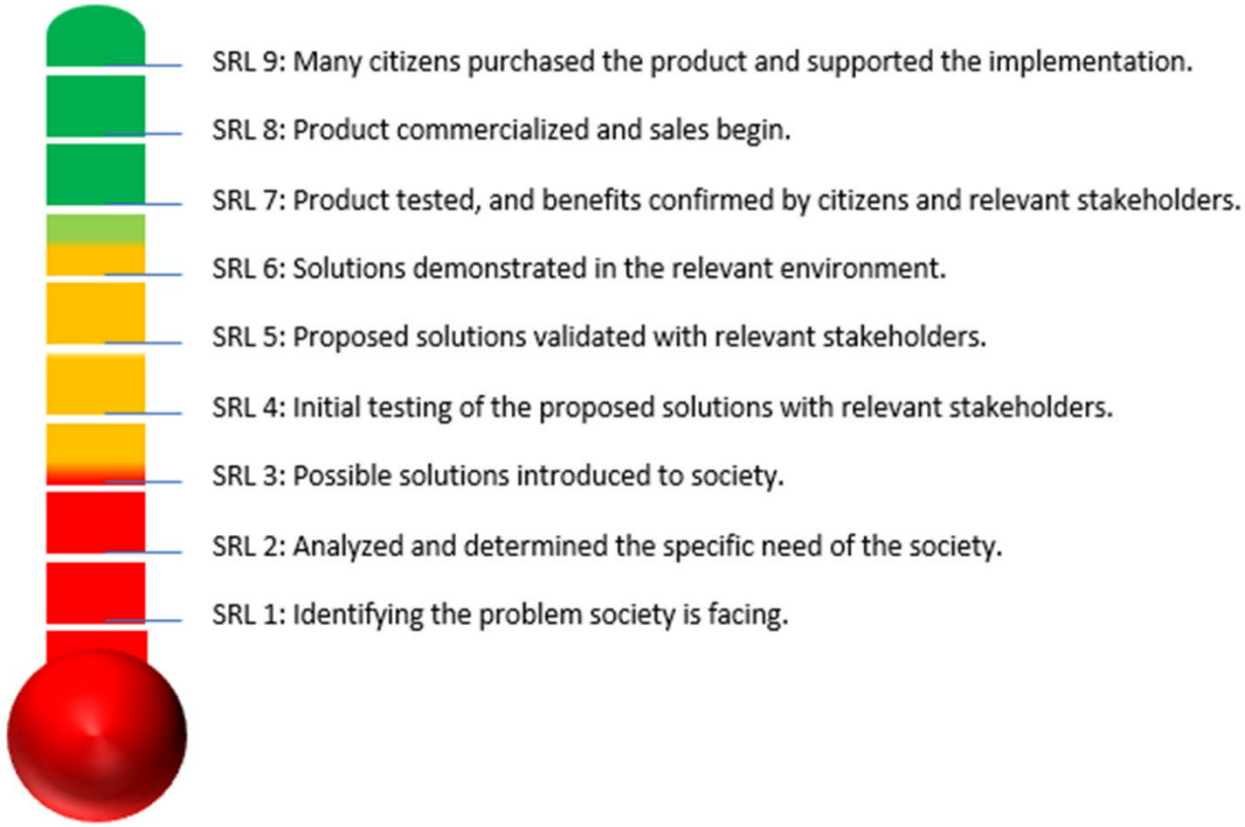
Stages SRL 7-9 include the end stages of the research project, including refining the solution(s), implementation and dissemination of results and/or solution(s). Here the plan for addressing the societal readiness on a practical level to gain impact, creating awareness, disseminating results, etc., will be carried out.

SRL as defined by Büscher et al., 2023

SRL	SoRA
SRL 1	Basic principles of societal readiness and social good defined.
SRL 2	Innovation-specific societal readiness concept formulated.
SRL 3	Societal readiness concept evaluated with stakeholders.
SRL 4	Societal readiness of prototypes evaluated with diverse stakeholders in test conditions.
SRL 5	Societal readiness of prototypes evaluated with diverse stakeholders in a limited way in everyday life.
SRL 6	Societal readiness of prototypes evaluated with diverse stakeholders examining full range of dissent through dialogue.
SRL 7	Demonstration of societal readiness and social good through experiment and formative evaluation with stakeholders in expected conditions.
SRL 8	Appropriation into everyday lives at a limited scale with demonstrable societal readiness and social good.

SRL 9	Innovation integrated into a diversity of everyday lives, as part of 'good life' and other society systems.

SRL as defined by Bhatti et al. (2023)



SRL	Description
9	The product is diffused in society, and many citizens buy the product.
8	Business development and product commercialization are completed, and the product's initial sales begin.
7	The citizens and the relevant stakeholders test the first product and confirm the benefits.
6	Establishing a business relationship by demonstrating the solutions with the customers and the relevant stakeholders.
5	Customers' and stakeholders' views confirm the proposed solutions' success rates in the specific area.
4	The proposed solution is tested by collecting the views of the customers and relevant stakeholders through pilot projects.
3	Suitable solutions that best fit the problems and awareness of these are provided to citizens and relevant stakeholders.
2	To specify the needs or problems of society, some market research is performed mainly based on secondary data.
1	In the initial stage, problems are identified, such as environmental problems, customer needs, or factors associated with human health, etc.

Source: Bhatti, H.J.; Danilovic, M.; Nåbo, A. A Multidimensional Readiness Index for the Electrification of the Transportation System in China, Norway, and Sweden. Future Transp. 2023, 3, 1360-1384. https://doi.org/10.3390/futuretransp3040075