Digital Service Innovation as a co-production of socio-technical assemblages oriented toward servitization

Author(s): Rodríguez, María Alejandra; Lepratte, Leandro; Yoguel, Gabriel; Rabetino, Rodrigo

Title: Digital Service Innovation as a co-production of socio-technical assemblages oriented toward servitization

Year: 2025

Version: Accepted manuscript

Please cite the original version:

Rodríguez, M. A., Lepratte, L., Yoguel, G., & Rabetino, R. (2025). Digital Service Innovation as a co-production of socio-technical assemblages oriented toward servitization. *Journal of Enterprise Information Management*. https://doi.org/10.1108/JEIM-04-2024-0216

Digital Service Innovation as a co-production of socio-technical assemblages oriented toward servitization.

Abstract

Purpose
Digitalization in precision agriculture incorporates state-of-the-art digital technologies. The transformation requires manufacturers to launch digital platforms and services. As a result, innovation ecosystems emerge. In turn, digital technologies introduce novelty into innovation processes. This socio-technical transition is critical to understanding Digital Service Innovation (DSI). Thus, it is necessary for a micro-founded analysis that biographizes the socio-technical assemblages between routines, artifacts, and humans that emerge from DSI processes. Against this backdrop, this study examines the co-production processes and the configuration of digital servitization ecosystems based on Routine Dynamics and Sociomateriality views and the Digital Service Innovation (DSI) perspective.

Methodology
The study builds on multiple in-depth case studies, including three precision agriculture machinery and services ecosystems. For each ecosystem, the biography of the co-production process of the technological solution that integrates different actors and artifacts as a sociomaterial assemblage is reconstructed. The qualitative data consists of in-depth interviews with managers in the case companies and stakeholders in each ecosystem. Three ecosystems were surveyed. Documentary information from websites and technical documents on the products and services were systematized and incorporated into the analysis as a form of triangulation.

Findings
The analysis of ecosystem biographies evidences that DSI processes involve co-production between routines, actors, and artifacts. This co-production implies moving from technology transfer relationships to the co-production of technological solutions oriented to digital servitization. New actors, digital artifacts, and changes in user practices emerge as translators of DSI processes towards digital servitization. Thus, the emergence of technological solutions must be understood as socio-technical assemblages.
The firms develop digital artifacts that allow the DSI process. The role of digital service platforms and users is critical in co-production. Digital artifacts based on algorithmic technologies perform automation and augmentation routines.

Originality
The study provides a complementary viewpoint between DSI approaches and the literature on Routine Dynamics and Sociomateriality. It explains in a micro-founded perspective, and based on biographies of the emergence of DSI ecosystems, how the relationship between digital artifacts, human practices, and routines become dynamic in the co-production of Technological Solutions. This perspective proposes that DSI processes are based on the co-production of socio-technical assemblages. Thus, sociomateriality is at the center of analyzing the role of artifacts and the networks of relationships they perform and configure with humans, generating strategies, organizational practices, and heterogeneous routine dynamics.

1. Introduction

Recent studies have examined the relationship between digital transformation and servitization processes (e.g., digital servitization and digital service innovation) and their impact on technological and business model innovation (BMI) and organizational changes (Bustinza et al., 2018; Linde et al., 2020; Paiola et al., 2022; Parida et al., 2019; Vendrell-Herrero et al., 2017). The above different but related studies strands emphasize the role of digital technologies as amplifiers and enablers of service innovation processes in manufacturing industries (Kohtamäki et al., 2022). Digital technologies as enablers are based on their open, configurable, and modular ontology. They also rely on data as semiotic, cognitive, and communicative artifacts (Alaimo & Kallinikos, 2024)..

In this context, digital transformation studies highlight the importance of transitions from digitization to digitalization (Ritter & Pedersen, 2020; Rodríguez et al., 2021). Based on this perspective, generating value in servitization is not reduced exclusively to the incorporation of technological artifacts and systems but also involves a redefinition of business strategies (Kohtamäki et al., 2022), changes in firm boundaries (Huikkola et al., 2020), new value co-creation relationships with different stakeholders (Lenka et al., 2017; Sjödin et al., 2020) and the emergence of innovation ecosystems (Kapoor et al., 2022). Accordingly, servitization studies have accounted for these transitions in manufacturing firms, involving innovative business and technological strategies to compete in markets with a growing presence of services based on digital technologies and platforms (Gebauer et al., 2020; Kohtamäki et al., 2019; Kowalkowski & Witell, 2020). Another significant body of literature has focused on building dynamic and digital capabilities in firms (Annarelli et al., 2021; Coreynen et al., 2020), as well as ecosystem-related capabilities for developing servitization processes that integrate digital transformation (Cenamor et al., 2019; Kohtamäki et al., 2020; Smania et al., 2022).

The above trend has led to a new research stream: digital servitization. It highlights the link between digital technologies and digitally-enabled services and critiques traditional categories of the relationship between technological innovation and services, emphasizing that service innovations can no longer be seen as disconnected from technological innovation processes (Opazo-Basáez et al., 2021). Moreover, recent contributions have stressed the concept of Digital Service Innovation (DSI), where "…both the service offering and the technological components that support it represent a single entity that can be adapted both in terms of the service itself and the technology in the based…" (Opazo Basáez et al., 2024:129).

Indeed, servitization scholars have recently proposed an agenda with significant topics, including characteristics, origins, challenges, learning processes, and market dynamics in DSI (Rabetino et al., 2024). Opazo-Basáez et al. (2024) argue that DSI studies require renewed interdisciplinary and convergent research perspectives. "… It encompasses an interdisciplinary approach, considering technological, organizational, and societal progress in a synergistic manner to scale up performance outcomes in service innovation" (Opazo Basáez et al., 2024:131). This position aligns with Rabetino et al. (2024), who consider DSI a complex phenomenon requiring interdisciplinary studies that analyze the technological, organizational, and human/societal factors that construct it. Similarly, Maric et al. (2024) express the need for a more comprehensive understanding of DSI to elucidate a complex phenomenon.

The above emergent agenda reveals gaps in existing research that open new avenues for moving the digital servitization field forward. Addressing the complexity of DSI processes implies recognizing that they are phenomena that relate organizations and digital technologies, linked to learning and knowledge generation processes that integrate technological solutions that transcend the limits of firms and emerge co-evolutionarily configuring ecosystems. These are processes that show an evolutionary trajectory that requires going beyond approaches of units of analysis focused on firm-centric cases, firm-customer relationships, and description of ecosystems. The Routine Dynamics perspective can make analytical contributions at the micro-organizational level to interpret DSI co-production processes and how they emerge from these socio-technical assemblages. Co-production implies translation dynamics where humans and artifacts exercise mutual agency and can align and converge around technological solutions. These technological solutions go beyond the merely artifactual (e.g., AI-based software) and configure socio-technical assemblages that are socio-material networks composed of both human elements (such as norms, practices, routines, knowledge, and skills) and non-human elements (such as tools, technologies, and artifacts). These components are not passive; artifacts, in particular, can influence and modify organizational routines and practices through their ontologies and functionalities (performative effects) and how stakeholders use them (D'Adderio, 2011; Feldman et al., 2021; Glaser et al., 2021; Lepratte & Yoguel, 2023).

Against this backdrop, there is a need to explore and examine the co-production processes of technological solutions that emerge from socio-technical assemblages of manufacturing firms and other relevant actors at the micro level. In doing so, a conceptual framework involving insights from the evolutionary tradition (Feldman, 2000; Feldman et al., 2021; Nelson & Winter, 1982) and the social studies of technology (STS) (Callon, 1990; Latour, 2007) can be beneficial towards filling, or shedding some light on, the above gaps. On the one hand, it incorporates concepts and propositions that improve the interpretation of DSI processes regarding the co-production of digital technological solutions and the emergence of socio-technical assemblages. Then, a vision of technological innovation connected to digital servitization processes can be established.

On the other hand, analytical perspectives of the historical reconstruction of micro-founded trajectories that relate strategies, practices, routines, and artifacts in the processes of DSI should be incorporated.

Specifically, based on Routine Dynamics and Sociomateriality views (D'Adderio, 2011, 2021; Feldman et al., 2016, 2021) and the DSI perspective (Opazo-Basáez et al., 2021; Rabetino et al., 2024), this study examines the processes of co-production of technological solutions, among diverse actors and artifacts explaining the performative effects, the emerging factors and the configuration of digital servitization ecosystems. The paper addresses two research questions:

> RQ 1. How do manufacturing firms transform their technological innovation routines in the face of socio-technical assemblages oriented toward DSI?
>
> RQ 2. What innovation models emerge when manufacturing firms move towards DSI?

We address the above questions based on a multiple, in-depth case study (Rohlfing, 2012; Stake, 1994; Yin, 2013) involving a historical examination of three ecosystem configurations oriented toward digital servitization in Argentina's machinery-equipment and precision agriculture services industry. This sector is selected because it is one of the most advanced in the country in servitization processes, along with Agtech firms, which in turn has been little explored in its analysis regarding ecosystems oriented to digital servitization[1]. Among its contributions, the paper proposes a conceptual framework that interprets the processes of digital service innovation (DSI) based on the transformation of innovation routines, the co-production of technological solutions, and the emergence

[1] For an analysis of capabilities and ecosystems for the case of agricultural machinery in Brazil, see Smania et al (2022). Our perspective focuses on agricultural machinery in Argentina at a deeper micro-organizational level, understanding organizational routines as building blocks of capabilities.

of ecosystems understood as socio-technical assemblages between actors and artifacts. The paper also offers some managerial contributions since it is evident that DSI processes require co-production strategies that go beyond the firms' limits and R&D capabilities. The emerging innovation models are open and iterative and must be managed by co-creating value based on digital servitization and technological innovation efforts.

The paper is organized as follows. After the introduction, Section 2 presents the theoretical framework, and Section 3 presents the methodology. In Section 4, the main processes of co-production and co-construction in both ecosystems are mapped and identified. In Section 5, he discusses emerging technology and innovation management models. Finally, the main conclusions and challenges for technology and innovation managers are presented.

2. Conceptual framework

2.1. DSI for servitization

Digitalization in manufacturers (e.g., in precision agriculture machinery) incorporates state-of-the-art technologies and triggers business model innovation. The transformation requires manufacturers to adopt digital technologies and platforms to offer services co-created with various users, driving servitization processes toward smart solutions (Kohtamäki et al., 2022). Thus, digital servitization is a transformation process towards intelligent solutions or product-service-software systems, which allow value to be created and captured through monitoring, control, optimization, and autonomous operation (Kohtamäki et al., 2019; Sjödin et al., 2020). While manufacturers globally tend to configure digital servitization strategies, processes, capabilities, and routines are transformed in industries in search of greater added value based on services that arise from the application of enabling digital technologies, generating technological innovation processes. Thus, co-production processes of product-service-software systems emerge in manufacturing firms with different actors, forming digital servitization ecosystems (Gebauer et al., 2020; Hein et al., 2020; Kohtamäki et al., 2019; Sklyar et al., 2019; Vendrell-Herrero et al., 2017). We consider here that the co-production of technological solutions is an organizational micro-process from which DSI (Digital Servitization Innovation) emerges. DSI is an emergent process of positive feedback between artifacts (technology systems, software, digital and non-digital asset devices) and routines (innovation, service provision, manufacturing production, and other organizational routines) in servitization processes between manufacturing firms and other relevant actors (e.g., users, stakeholders) (Glaser et al., 2021; Lepratte & Yoguel, 2023)

Therefore, we must introduce the DSI concept to understand how manufacturers' transformations involve designing, distributing, customizing, and consuming technological solutions built on products and digitally enabled services (Raddats et al., 2022). Following previous studies, we assume that Digital Service Innovation (DSI)

"… refers to developing customer-centric services and related business model configurations allowed by digitalization, using technology and software as enablers of information flow and stakeholder co-creation in (eco)systems to integrate digital and non-digital assets into (device-dependent or device-independent) offerings and create valuable customer experiences and value for businesses through improved operations, new revenue streams and data gathering regarding the use of technology to develop future offerings" (Rabetino et al., 2024:191).

As a result of DSI processes, innovation ecosystems emerge based on digital technological solutions (big data, artificial intelligence, robotics, and other algorithmic technologies) (Kohtamäki et al., 2022; Raddats et al., 2022). In turn, algorithmic technologies (including data-driven and artificial intelligence) introduce novelty into service innovation processes, raising the importance of understanding these digital artifacts' performative role in firms' routines (D'Adderio, 2011).

New approaches to the dynamism of organizational routines incorporate artifacts from the tradition of social studies of technology (Callon et al., 2002; Latour, 2007). Artifacts are intermediaries that generate, change, and sustain routines (D'Adderio, 2011). Humans (organizations) and artifacts configure materialities with performative effects on organizational practices, which sustain structures and, in turn, enable their changes (Feldman et al., 2021; Leonardi et al., 2012). Artifacts serve as templates for humans (organizations) to perform routines for generating and guiding behaviors. They also give consistency and coordination to organizational practices and the socio-material networks they form. They exert agency over organizational practices (routines) and cannot be considered external tools or objects (Glaser et al., 2021; Kallinikos et al., 2013). Herein lies the importance of the turn in materiality studies in organizations that provide concepts conducive to interpreting the DSI, primarily because of the ontological nature of digital artifacts that pose a material and symbolic duality, which differentiates them from other exclusively physical artifacts (D'Adderio, 2011, 2014; Kallinikos et al., 2013). Digital artifacts are configurable, flexible to human requirements, reconfigurable by humans, and able to be replicated, stored, and transmitted immediately and ubiquitously. The ontology of digital artifacts offers DSI the possibility of integrating digital technologies with servitization processes, transforming the vision of DSI processes from single firms to socio-technical networks.

2.2. Socio-technical transition and DSI

Embracing digitalization demands integrating digital technologies and harnessing their power to elevate business performance. However, transitioning manufacturers towards models based on digital servitization introduces more intricate socio-technical structures and processes (Hinings et al., 2018; Münch et al., 2022). This requires incorporating diverse actors and digital artifacts into heterogeneous networks and orchestrating new routines and behavioral patterns (D'Adderio, 2011; Glaser et al., 2021; Lepratte & Yoguel, 2023). These transformation processes are not isolated but occur within broader socio-technical transitions (Geels, 2004, 2020). Socio-technical transitions involve understanding the co-production of technological solutions and DSI processes in contexts where technological change is interrelated with long-term social, cultural, and institutional changes. It is multi-level and actor-driven, implying that micro-processes of co-production are related to changes in the socio-technical landscape, existing technological regimes, and the generation of technological innovation niches. Several manufacturing industries are oriented toward incorporating digital and algorithmic artifacts and resolving environmental sustainability problems (Bockshecker et al., 2018; Geels, 2020; Pelli & Lähtinen, 2020). This is a scenario of sociotechnical transition that agricultural machinery is currently undergoing.

Our framework proposes that digital service innovation (DSI) emerges on dynamic socio-technical interactions across the boundaries of contextual (external-internal) and organizational (internal-external) space and time-situated actions. This interplay emerges from a systemic convergence of Digital Transformation (DT) (Warner & Wäger, 2019) and servitization (Rabetino et al., 2018). Manufacturers and other actors interact as an actor-rule system (Geels, 2020), leading to DSI as part of open-ended and non-linear socio-technical transitions (implying contextual and organizational connections). This development stems from an intensifying convergence of service-oriented digital technologies (Kohtamäki et al., 2022; Münch et al., 2022; Sjödin et al., 2020).

These DSIs imply changes in user management routines and practices, transformations in traceability methods, institutional redefinitions, new infrastructures, and reconfigurations of business models. Furthermore, on a micro level, it highlights the importance of artifacts (digital and algorithmic technologies) in transforming and emerging new ecosystems, as stated above (Hein et al., 2020; Kohtamäki et al., 2022; Rodríguez et al., 2021). Therefore, a socio-technical transition is crucial for understanding Digital Service Innovation (DSI) processes. Consequently, incorporating a micro-foundational analysis of the DSI perspective becomes essential (Geels, 2020; Huikkola et al., 2020; Opazo Basáez et al., 2024; Rabetino et al., 2024; Sjödin et al., 2020).

Beyond the perspectives of singular or comparative case analysis, DSI processes require evolutionary perspectives that reconstruct trajectories of co-production and emergence of ecosystems (Rodríguez et al., 2021). Thus, insights from the actor-network theory (Latour, 2007), implicit in the Routine Dynamics perspective, can bring a critical contribution worth considering (Feldman et al., 2021; Glaser et al., 2021). This perspective delves into the "biography" of the socio-technical assemblages that emerge from DSI processes, focusing on the interplay between routines, digital and algorithmic technologies, and humans (Glaser et al., 2021; Lepratte & Yoguel, 2023). The biography perspective focuses on reconstructing, historically and from situated actions, the micro-organizational processes of co-production of technological solutions, identifying the sustainability, enactment, and emergence of networks of actors, artifacts, and organizational practices (routines) that can form socio-technical assemblages.

2.3 Routine Dynamics, artifacts, and DSI

Our primary assumption is that Digital Service Innovation (DSI) is a process that transforms routines through the co-production of technological solutions in manufacturing companies. This process involves the emergence of innovation because of the co-production of services based on digital and algorithmic technologies between manufacturers and other relevant actors. To analyze the micro-foundations of DSI, we adopt the Routine Dynamics perspective and its contributions to artifacts and sociomateriality (D'Adderio, 2014; Feldman et al., 2016, 2021; Glaser et al., 2021; Parmentier-Cajaiba et al., 2021).

Routine dynamics (D'Adderio, 2011; Feldman et al., 2016) change our understanding of DSI by emphasizing the materiality of socio-technical context at the micro level. It rejects the view of digital technologies as solely "smart tools" for data processing or productivity boosters. Instead, it sees them as complex artifacts embedded in dynamic socio-technical systems oriented to servitization (Münch et al., 2022), co-producing and co-produced by routines, actors, and institutions (Bijker et al., 2012). In turn, the Routine Dynamics perspective understands that innovation routines are not "meta-routines" (e.g., deliberate R&D actions) but that due to their co-evolution with the materiality of digital artifacts, organizational routines are possible sources of permanent incremental innovations.

Technological solutions based on digital and algorithmic technologies are socio-technical assemblages that co-produce routines and artifacts (Bijker, 2010; V. L. Glaser et al., 2021; Pinch, 2008). Co-production is a socio-technical process enacted and emerged between actors and artifacts and implies translation effects between ostensive and performative dimensions of routine dynamics (D'Adderio, 2011; Feldman et al., 2021; Glaser et al., 2021; Lepratte & Yoguel, 2023). Digital artifacts embedded in Technological solutions enacted new service routines with the actors participating in the co-production processes. Co-production involves translations between actors and artifacts (Callon, 1990; Glaser et al., 2021; Latour, 2007), interpretative flexibility concerning the technological solution (Bijker, 2010; Oudshoorn & Pinch, 2013), and the emergence of a distributed cognition system (Hutchins, 2006) where expert, tacit, and codified knowledge from a multiplicity of actors converge. Translation means aligning actors and artifacts in heterogeneous, unstable networks that seek to assemblage with some strategy or common goal around a technological solution (Akrich et al., 2002; Callon, 2004). In this process, there are phases of interpretative flexibility, that is, different relevant actors (e.g., technologists, managers, users, among others) who co-design the functionality that will be temporarily dominant (Bijker, 2010; Kallinikos, 2011; Oudshoorn & Pinch, 2013). The technological solution to the emergence is materialized in a series of specific skills and knowledge, artifacts, and routines identified with the socio-technical assemblage (D'Adderio, 2011; Leonardi et al., 2012).

Applying these ideas to understanding the micro-processes of DSI, we consider that the emergence of socio-technical assemblages oriented to digital servitization changes the dimensions of service routines. On the one hand, the user experience service plans (ostensive dimension) and, on the other, the actualization of the real experience resulting from interactions between users and other intermediaries (performative dimension). In both dimensions, digital and algorithmic artifacts make it possible to drive two significant types of innovations guided by DSI: the automation of routines and the augmentation of human cognitive skills (Lepratte & Yoguel, 2023; Raisch & Krakowski, 2021). Changes in user routines are sources of value co-creation (Rabetino et al., 2024).

From these perspectives, DSI is embedded (Deken et al., 2016; Deken & Sele, 2021) in generating, emerging, and changing routines. These routines are co-produced by contextualized organizations (Feldman et al., 2016) and situated action (Suchman, 2007), where humans and artifacts interact to configure socio-technical assemblages (Callon, 1990; D'Adderio, 2011; Latour, 2007).

The socio-technical assemblages materialized translations and intermediaries (human and artifacts), triggering changes in organizational routines, distributed cognition systems, forms of appropriation of innovations, user practices, business models, and governance of the emerging ecosystem (Kohtamäki et al., 2022; Parmentier-Cajaiba et al., 2021; Rodríguez et al., 2021).

3. Methodology

3.1. Research Strategy

The study draws on an inductive approach that deeply analyzes multiple cases to answer our research questions (Eisenhardt, 1989; Yin, 2013). Initially, an in-depth analysis of the cases was proposed to reconstruct ecosystem emergence trajectories concerning the co-production of technological solutions that integrate multiple actors and artifacts. This perspective is supported by methodological contributions on studies of biographies of organizational artifacts and routines at the micro-organizational level (Glaser et al., 2021; Lepratte & Yoguel, 2023) and the research perspective of ANT that is based on a reconstruction of the trajectories of socio-technical networks in an "in the making" scenario (Callon, 1987). That is, to follow the actors and artifacts in their co-production processes, considering the phenomena of emergence and networks that lead to the configuration of socio-technical assemblages (D'Adderio, 2011; Glaser et al., 2021). After analyzing the biography of the emergence of each ecosystem, we propose a comparative analysis of each trajectory and configuration of sociotechnical assemblages to identify common patterns and differences between them (Greckhamer et al., 2018).

3.2. Research context

Agriculture and agribusiness are currently going through a socio-technical transition to face challenges of greater sustainability and productivity (Santos Valle & Kienzle, 2020). The growth in the demand for food, the dilemmas of climate change, the new trends of ecological consumption, the assurance of traceability in agri-food systems, and changes in regulatory frameworks for international trade are some of the factors that are contributing to changes in technological regimes and agribusiness models (Abbasi et al., 2022).

Therefore, scholars highlight the role of digital technologies in transforming agricultural activities. This would be driving a transition from Agriculture 3.0 based on ICT and automation to Agriculture 4.0, incorporating IoT, artificial intelligence, and Big Data, among other technologies aimed at digitalization and platformization. This socio-technical transition begins with technologies applied to precision agriculture and moves towards a Smart Farming model based on autonomous production processes and ubiquitous agriculture sensors connected to digital platforms (Javaid et al., 2022).

These processes of technological change reconfigure socio-technical assemblages in agriculture. New actors and artifacts emerge, and others must be transformed to respond to the dynamics of transformation. Many startups are focused on providing digital transformation services and platformisation of agricultural activities. In this transition scenario, the traditional manufacturing sectors related to machinery and equipment for agriculture must innovate to adapt to the digital transformations. Thus, new challenges and opportunities appear in this last type of firm that impact their traditional ways of innovating based on processes and products.

Agricultural machinery and equipment have already undergone significant changes to incorporate the package of technologies for precision agriculture (Agro 3.0) into its products, seeking to automate mechanisms and promote connectivity possibilities to networks and platforms. However, the transition to the Agro 4.0 package focused on Smart farming requires other innovations, more focused on incorporating connected services with the technological package of digital and algorithmic artifacts related to the exploitation of large volumes of data, artificial intelligence, and autonomous learning promoting precision agriculture. The challenge for precision agriculture machinery and equipment firms is to transform their routines, oriented towards improvements and innovations in manufacturing processes and products, to Digital Service Innovation processes.

3.3. Case selection

According to our theoretical and purposeful sampling, three precision agriculture solution providers from Argentinian Pampas and the related services ecosystems were selected as cases for the study's purpose (Eisenhardt, 1989; Eisenhardt & Graebner, 2007). Four criteria were used to select the ecosystems: 1. that they contain at least one agricultural machinery firm with a digital servitization strategy, 2. that this strategy evidences deliberate or emerging responses to the socio-technical transition in agriculture, 3. that other actors also participate in the development of digital technological solutions, 4. that the technological solution has been on the market as a technological and service innovation for at least one year, 5. that the technological solution has been on the market as a technological and service innovation for at least one year, and 6. that it has been in the market for at least one year.

We labeled the ecosystems Ecomaq1, Ecomq2, and Emaq 3. (Table 1). Each ecosystem was defined to deepen the biography of the technological solution's co-production processes and the ecosystem's emergence from the year in which each manufacturing firm (MAQ1, MAQ2, MAQ3) defined digital servitization strategies. For each ecosystem, the biography of the co-production process of the technological solution that integrates different actors and artifacts as a sociomaterial assemblage is reconstructed (Callon et al., 2002; Glaser et al., 2021; Lepratte & Yoguel, 2023; Spring & Araujo, 2017).

TABLE 1

We studied each ecosystem to investigate and analyze different moments of the co-production and materialization of DSI processes in manufacturing and their interaction with other actors and artifacts of the assemblages. This research framework was chosen because the socio-technical transition in the precision agriculture machinery equipment and services ecosystems is happening. As said in section 3.1, according to the Routine Dynamics perspective, the so-called "in the making" from the Actor-Network Theory is a well-known empirical approach to understanding the biography of the social construction of artifacts, intermediaries, and translations. This perspective allows a vision of the micro-processes of DSI by analyzing how the relationship between digitalization and servitization occurs over time in ecosystems based on product manufacturing companies. It examines the complexity of the relationships embedded in DSI processes considering technological, organizational, and human aspects (Opazo Basáez et al., 2024; Rabetino et al., 2024).

3.4. Data Collection and Analysis

The qualitative data consists of 12 in-depth interviews with managers in the core companies and key stakeholders in each ecosystem. Data collection was carried out in two phases. The first consisted of interviewing core company members that manufacture machinery and equipment for the central technological solution of the ecosystem to be rebuilt. Interviewees from manufacturing companies examined their technological innovation processes based on digitalization and servitization in the interviews. From this discursive evidence, the new actors and artifacts (technologies) that made up the network of components of the socio-technical assemblage were linked. Based on these interview statements, the relevant actors and artifacts in the co-production process of the technological solution were analyzed and selected. This is where the second stage of interviews begins, which follows snowball-type selection criteria. The interview phases ended when there was recursive information among the interviewees regarding the artifacts and actors that made up the technological solution and gave rise to the emergence of the ecosystem. According to these procedures, 13 interviews were conducted, with approximately 710 minutes of audio recordings (Table 2).

TABLE 2

For each dimension of the study, open-ended questions were used in the interviews, and more specific questions were used according to the analysis of the experiences and biographies of each case. Each interview lasted between 60 and 90 minutes and was recorded on Zoom. The interviewers made notes and then shared them to strengthen the process of analyzing them concerning the questions of the study and the theory. All recorded interviews were transcribed verbatim and analyzed. Additional documentation was also used to validate the data.

For data analysis, the coding of the interviews was organized according to the relevant terms and phrases, looking for conceptual patterns according to the theoretical perspective and the scope of the study (Glaser & Strauss, 2017). Two members of the research independently analyzed the interviews and coded them. They were then pooled, and the first-order categories of code scheme combination emerged. These categories represent the processes of co-production, digitalization, and servitization carried out by the actors. They also represent the leading technologies used. From identifying the relationships of these categories, a global conception of the ecosystem's emergence and technological solution according to the materialization of the socio-technical assemblage emerged. Finally, these issues were considered in a more aggregate and abstract sense (Braun and Clarke, 2006; Gioia et al., 2013), making it possible to understand the DSI process and its results in terms of transformations towards digitalization and servitization of the manufacturers analyzed (see Figure 1).

FIGURE 1

3.5 Research quality

The study followed a research design that ensured external validity criteria that allowed its future replication (Golafshani, 2003). Thus, the criteria for selecting the multiple cases analyzed to focus on the study of DSI processes from the literature used were established. The context of the study has been presented according to the perspective of the socio-technical transition, which is a propitious criterion for developing other similar research. Empirical and conceptual patterns have been identified in the three ecosystems analyzed as cases that would allow the generation of new hypotheses and an upgrade in the scale of quantitative studies in the future. In addition, data between triangulation interviews and interviews with documented information have been implemented. Documentary information from websites and technical documents of the products and services was systematized and incorporated into the analysis as a form of triangulation (Yin, 2014). The theoretical triangulation between the contributions of the Routine Dynamics and DSI perspective has given consistency to the constructed framework and allowed versatility of categories and concepts for its interpretation.

Regarding reliability, the perspective of multiple case analyses, the findings achieved in the study, and the theoretical propositions that have been constructed allow this type of research to be replicated in other industries. The protocol for selecting the cases, identifying a period for the reconstruction of the co-production trajectory, and the emergence of the ecosystem are central dimensions of the study, as well as the comparison between cases. The interviews with the different actors involved in the co-production process also allow for greater interpretative capacity about the moments of the biography and to check the data, information, and categories that emerge from the inductive path (Alvesson & Sandberg, 2013; Nag et al., 2007)

4. Findings

In each biography of socio-material assemblages' co-production, we identify digital service innovation (DSI) processes, relationships between actors and artifacts, changes in organizational routines, distributed cognition systems, forms of appropriation of innovations, user practices, business models, and governance of the emerging ecosystem.

4.1 Ecomaq 1

MAQ1 is a company dedicated to producing agricultural machinery, implements, and services related to agriculture. It was founded in 1975. It has an outstanding technological trajectory, pioneering Latin America in producing self-propelled equipment with autopilots. The evolution of its products has been accompanied by the technological advances that have taken place in the sector to date, both in machining[2] and precision

[2] He has achieved technological developments in liaison with INTA researchers, for which he has filed 16 invention patent applications, the most recent being filed in 2018 jointly with INTA.

agriculture technologies[3]. This has led it to be the leading company in Argentina in the field *of sprayers* and to have a presence in markets such as Australia, South Africa, Eastern European countries, and Mexico. In 2019, it was acquired by a well-known multinational agricultural machinery company (JD).

Over the years, its relationship with users was focused on the sale of spraying machinery, and its business model was focused on after-sales products and services such as repairs and technical (human) monitoring of the condition of the products.

Since 2018, MAQ1 has driven changes in its business strategies in the last five years by focusing on the "*provision of integrated solutions and advanced services*" (*PMM-Maq1*) for its clients.

> *"We knew we wanted to go on the service side, take information, remotify the information, but it was all very imprecise to define. So, we started open discussions for many months with customers and, on the other hand, with the dealers who had to sell the machine. We want the strategy not to come from the factory but from what is needed in the market."(PMM-Maq1)*

The process of redefining its business model towards the progressive integration of services is partly the consequence of a strategy adjustment as an actor-rule system of a socio-technical transition. The emergence of precision agriculture in the global market ushered in a socio-technical transition towards digitally based forms of crop management and food production. This generated competitive pressure from the leading brands in agricultural machinery in the international market. On the other hand, the permanent dynamism of the no-till technological regime incorporates sustainability standards. These

[3] Between 2010 and 2020 it was permanently integrating electronic equipment, with specific sensors and software and controller devices and/or actuators for variable rate application in sowing and section cuts in spraying, sowing and spraying monitors, for control of seed drop, dosage, generation of sowing and spraying maps, and general monitoring of sowing and spraying work.

standards demand compliance with laws and regulations related to phytosanitary products and promote initiatives for good agricultural practices.

> *"Spraying can be risky from an environmental and health point of view if it is not well managed. With the transformations in our products and the services we add, we are looking for remote and permanent monitoring to make spraying more precise while avoiding risks. That allows you to learn from the data and optimize the accuracy of the application." (PMM-Maq1)*

The redefinition of its business strategy involved the development of new technological solutions. In this way, the co-production of a technological solution was carried out with other actors. The STMaq1 technological solution aims to integrate products (spraying machinery) and advanced services (digital platform with monitoring, control, and optimization system for phytosanitary applications) to optimize the client's agricultural processes concerning spraying and other precision agriculture practices. This is a critical issue in the DSI process in MAQ1. They did not have the skills and capabilities to transform their production and innovation routines that STMaq1 could develop. The development of STMaq1 involved redefining MAQ1's innovation and production strategies. Its traditional innovation management focused on its area of electromechanical and metallurgical engineering, which required the adoption of new routines, coupling these activities to the interaction with other actors in the STMaq1 co-production process. Here, an Agtech firm, an IT web development consultancy, MAQ1 concessionaires, users, and science and technology institutions appear relevant.

> *"We don't have people who do platform design and development. We requested that from Agtech1, but always with interactions with our customers, and from there, it developed (STMaq1), and if I tell you today, it is different than last week and much more different than four years ago and in a*

month it will be much more different as well, I mean, the reality is that it is very dynamic, the product and services are very much in motion." (PMM-Maq1)

The co-production process transformed the routines of innovation and production in MAQ1 by socio-technically assembling other actors and the artifacts they develop. That process involved boosting DSI dynamics. In other words, the digital transformation of traditional machinery artifacts made it possible to offer Smart services. The DSI process promoted, with limited rationality, processes of exploration and co-construction of knowledge.

"(MAQ1) asked us for more and more functions for spraying until we ended up developing a mathematical model that integrated the practical knowledge that its clients had with a mathematical model with scientific information, with papers, with academic works." (CEO-AGT1)

In this way, the routines of R+D, production, and development of services were connected with electromechanical sowing and spraying monitoring devices, the control devices and/or actuators for the spraying section cutting system, intelligent product application system, analysis engines and mathematical models (algorithms), digital application platform, communication networks, product software and hardware, gateway to external information sources, and integration tools with enterprise systems (ERP, CRM, and PLM).

These changes involved the co-construction of knowledge and the co-creation of value embedded in DSI dynamics. These dynamic processes of a systemic nature between actors (firms and institutions) and artifacts, mainly digital, give rise to the emergence of an ecosystem oriented towards digital servitization. In this case, the **Ecomaq1**.

The socio-technical assembly of **Ecomaq1** (Figure 2) is established with three main actors in the **STMaq1 co-production process**. The governance structure is established with MAQ1, which provides the routine system of machinery production, its techno-productive capacities and agronomic and market knowledge, and its potential growth and investment when absorbed by a multinational (**JD**). **AGT1** is an Argentinian Agtech company founded in 2012, which co-produces with MAQ1 a real-time monitoring and control system for agricultural machinery based on an IoT solution that captures data in real-time[4], transforms it into knowledge from mathematical and algorithmic models and (UNIMAP) makes it available to the operator through a digital platform adapted exclusively for[5] MAQ1 customers.

"We added in STMaq1 the knowledge of experts in spraying and knowledge that was not even in spraying experts, we began to put it in UNIMAP, and it began to become more of a tool than a control system, and we added a tablet and a computer in the cabin so that the operator has all this information and so that the operator receives all these recommendations and all this information" (CEO-AGT1).

On the other hand, **BIT1**, an Argentine company formed in 2019, a specialist in digital business design, co-produces with MAQ1 the digital platform and mobile app for technical assistance and communication with customers.

"And now we are redesigning the portal for the dealerships since they (dealers) are great protagonists in this change from a product sale to a service because the dealership provides the

[4] Data captured from climate information systems (temperature, humidity, wind speed and direction), geopositioning, and machinery sensors that allow monitoring and controlling variables such as sowing speed, seed density, drift index, plugging and evaporation, quality of application of phytosanitary products, harvest yield, grain moisture, path analysis, among others.
[5] The solution is factory-installed and from the second year onwards, customers must pay an annual licence (AGT1) to maintain the accompanying services provided by the monitoring and control system of machinery and work in real time.

service. Different dealerships are more advanced or not in this matter of providing services, but they all realize that it is the way and that the machine itself is already a commodity, so it has to have services on the way back to build loyalty and to really keep you in mind and that they can also continue billing" (MM-Bt1).

The technological solution **(STMaq1)** of the **Ecomaq1** is not definitive and implies permanent co-production between the actors' work teams (R+D, product development), including users and concessionaires. On a technological level, MAQ1 and AGT1 are working on updating and developing new functionalities of the solution that may arise from the feedback of information and knowledge from customers, as in the replication of the technological solution in the remaining MAQ1 product lines and the integration to JD's global platform[6]. The latter implies new learning and interactions with areas of R+D and commercialization. MAQ1 and BIT1 are working on updating the digital customer platform and developing a platform to offer more services to customers through their dealer network. In addition, the AGT1 and BIT1 work teams co-construct knowledge under the coordination of MAQ1 since there is feedback between the AGT1 monitoring system and the customer assistance system and dealer portal developed by BIT1.

At the same time, AGT1 expanded its innovation strategy concerning Ecomaq1 and linked up with R+D centers[7] to optimize the algorithms of the monitoring system and automate the spraying solution as much as possible. Figure 1 shows a diagram of the emergence of Ecomaq1. The technological solution (STMaq1) is a result of processes of co-production (black arrows) and co-construction of knowledge (green arrows). The

[6] One of the most important multinational agricultural machinery companies in the world.
[7] It has links with the Research Center for Computational Methods (CIMEC, CONICET-UNL) and the Plapiqui R+D+i Institute (CONICET-UNS).

MAQ1 product system integrates with other systems and information sources (orange arrows).

Figure 2. Ecomaq1 emergency

4.2 Ecomaq2

MAQ2 is an Argentinian company that produces self-propelled and trailing fertilizers and related services. It was born in 2005 from an innovation that introduced a technological solution in the field of fertilization that did not exist in the Argentine market: *variable dosing by belt proportional to the advance*. The diffusion of this technology quickly positioned the company as a leader in the Argentine market.

However, the growing advances in digital agriculture and the technological regime of no-till that requires management, control, and monitoring of soil fertility and nutrition[8] led the company to redefine its business model. In doing so, they redefined their innovation strategy towards a DSI process. Along its evolutionary path, its techno-productive routines allowed it to achieve innovative incremental solutions[9] that optimize variable fertilizer dosing systems based on the growing incorporation of precision agriculture technologies and promoting advanced services to its customers.

These technological advances, in principle, were made in internal engineering and, in some cases, in collaboration with researchers from INTA Balcarce and the Faculty of Agricultural Sciences of the UNMdP for developments and tests. To develop the digital transformation process of their products, they needed to change routines and enhance

[8] Ministry of Agriculture, Livestock and Fisheries (2021), *Soil fertility and nutrition*. https://www.argentina.gob.ar/sites/default/files/informe-fertilidad-nutricion-suelos-200mt-magyp.pdf

[9] As of 2017, the company filed six patent applications, all of which were granted and four are still pending.

digitalization capabilities. Identifying a strategic partner (AGT2) allowed them to generate a DSI process. This process led to the emergence of the Ecomaq2 aimed at digital servitization.

The configuration of **Ecomaq2** (Figure 3) is established with two main actors who configured a socio-technical alliance called the "Collaborative R+D Program".[10] MAQ2 brings its expertise in soil fertilization, and **AGT2**, a technology company that develops information systems for agriculture, was founded in 2014. Both co-produce a digital agriculture platform to support and solve agribusiness decisions. AGT2 is mainly key in its contribution of knowledge on software and artificial intelligence and expertise in crop monitoring systems.

In the co-production process of the STMaq2 technological solution, the routines of both companies make up a socio-technical assembly with artifacts such as crop monitoring monitors, variable nutrient dosing, smart product applications, analysis engines, and mathematical models (algorithms), digital application platform, communication networks, product software and hardware, integration tools with enterprise systems (ERP, CRM, and PLM), UAV (drone), and AI tools.

The technological solution they co-produced (**STMaq2**) thus consisted of a Smart solution that integrates products (fertilizing machinery) and advanced services (digital platform with AI-based monitoring, control, and optimization system for nutrient applications), aimed at optimizing the customer's agricultural processes and yields. The technological basis is integrating the STMaq with UAVs and computer vision with AI.

> *"We are not giving additional functionality to a product; we are giving all the support infrastructure to a company to digitize its products and services, and the challenge we have is much more ambitious*

[10] AGT2 promotes this same "Collaborative R+D Program" with a well-known biotechnology seed company.

because, ultimately, we have to make a company like MAQ2 compete against large multinational companies. So the solutions and tools that we have to put in the hands of a company like MAQ2 have to be of global quality." (CEO-AGT2)

Regarding the co-production of STMaq, they consider:

"(...) it has a one-way way from the attachment (from Maq2) to the platform, from the platform to the attachment, with the possibility of generating a prescription map and sending it to the machine to execute the dosing. Then, a process goes back from the machine to the platform with all the data from the application. This allows this data-driven management system to be fed in, comparing a variable fertilizer application map with a yield map of a combination registered on the platform. In this way, it is possible to know how the crop performed in which a certain dose of fertilizer was applied variably." (CEO-AGT2)

The ecosystem's governance of co-production processes is formalized, with objectives and timelines, being led at the beginning by the engineering departments of MAQ2 and AGT2. They also adapted the MAQ2 telemetry system to the AGT2 digital platform. Clients and specialists from INTA and the Faculty of Agricultural Sciences of the UNMdP also participated in this process for validations and field tests.

In terms of the processes of co-construction of knowledge and new co-production of technological solutions, **Ecomaq2** generates new routines and capabilities from the creation of an "Agtech and Robotics" department and the incorporation of a specialist in agricultural machining and robotics in MAQ2. This department coordinates R+D+i projects in the ecosystem.

> *"This Head of Agtech and Robotics is the one who started to accelerate this process of validating connectivity, especially of the machine with the platform and this two-way path between the machine and the platform." (MM-Maq2)*

The technological solution of **Ecomaq2** is not definitive and involves permanent co-productions between the actors, including the clients and the technologies. On a technological level, MAQ2, through its "Agtech and Robotics" department, and the AGT2 development team are working on improving the technological solution and innovating in services by incorporating new applications to the platform. One is to measure fertilizer application quality in real-time, consisting of a drone with artificial intelligence connected to the platform and agricultural machinery.

The **Ecomaq2** actors foresee that in the coming years, the agricultural business will be crossed by the transition towards digital transformation, mainly by robotics and autonomous equipment, which is why they consider the expansion and/or evolution of business and technological strategies. In this sense, they progressively incorporate issues related to the transition to sustainability.

> *"The software can interpret what is happening with inputs through data science engines and how to make agriculture more efficient, sustainable, and productive. Here, it is essential to interact with customers and provide them with all the infrastructure that Agtech2 must use to help them digitize their business. In this way, we measure our knowledge and trajectory in fertilization with the digitalization proposals that Agtech2 can give them." (MM-Maq2)*

At the same time, they are exploring with a robotics partner for agriculture. Here, there would be new processes of co-construction of knowledge and co-production. For this part, AGT2 carries out technological and market surveillance for innovation and links with academia[11].

Figure 3 shows a diagram of the emergence of Ecomaq2. The technological solution results from co-production (black arrows) and co-construction of the actors' knowledge (green arrows). The MAQ2 product system integrates with other systems and information sources (orange arrows).

Figure 3. Ecomaq2 emergency

4.3 Ecomaq3

MAQ3 is an Argentine company dedicated to producing grain harvesters, implements, and services related to agriculture. It was founded in 1949, and its products have evolved in machining and threshing systems (conventional-axial) and precision agriculture technologies, following the technological advances in mechanics, pneumatics, and electronics that have occurred in the sector until today. Its track record of innovation and quality allowed it to overcome the ups and downs of the Argentine economy and stay in the market, being the only Argentine combined harvester manufacturer from the 2001 crisis to 2021. It currently ranks fourth in the market share after foreign companies John Deere, Case, and New Holland. It exports to countries in Latin America, Europe, and southern Africa.

Technological advances, in principle, were made according to the capabilities of the engineering and internal development area, such as technological learning achieved

[11] INIA Uruguay, CONICET-UNC.

with visits to specialized suppliers (Germany and the USA) and, in some cases, in collaboration with INTA[12] in PROPECO.

In the last three years, MAQ3 has driven changes in its business strategies to *provide integrated advanced product and service solutions* for its customers. This was mainly due to the emergence of global market dynamics around digital agriculture and socio-technical transitions towards forms of production based on digital technologies, coupled with the competitive pressure exerted by leading brands in agricultural machinery. The benefit of MAQ3 is that it can access niche markets that request this type of solution.

> *"The competition has this technological solution, and a niche market requires it because, for example, the sowing and harvesting pools are lovers of these systems because they control them remotely. So this new business strategy allowed us to access that customer, (...) there is a portion of 10 or 15% that needs it. Without this (the technological solution), we don't enter that market or that portion." "It classifies us better in the market; we access that portion... It helps." (MM-Maq3)*

These changes implied the emergence of new R+D routines in MAQ3. An Electronics Department was created where all the infrastructure and software of the top-of-the-range version of the combine harvester was designed and developed. From there, processes of co-construction of knowledge and co-production of technological solutions with strategic partners were promoted. These dynamic processes are systemic between the DSI process actors (firms and institutions) and technologies.

[12] Participation in the Grain Harvest and Postharvest Efficiency Project (PROPECO), organized by INTA. This program promoted inter-institutional actions that favored the dissemination, experimentation and generation of technologies that increase harvesting efficiency. He participated in the 2003 and 2022 campaigns.

The STMaq3 technological solution they co-produce is an integrated Smart Solution of products (harvesting machinery) and advanced services (monitoring and control system of harvesting tasks) to optimize the customer's agricultural processes.

> *"The combine today is a computer on wheels. Before, it was purely mechanical; then it was hydraulics and mechanics, then electronics were incorporated until we reached digital and platforms. Moreover, the first platforms were rigid, but now, we have to make them flexible platforms that copy the terrain. That took years of development. You also have to keep in mind that genetic developments, let's say of the seed, also have a huge influence on the machine." (R&DM-Maq3)*

In this way, the DSI process results in a socio-technical assemblage of innovation, production, and service delivery routines with artifacts such as crop yield monitor, smart product applications, application platforms, communication networks, product software, and product hardware, gateway to external information sources, integration tools with enterprise systems (ERP, CRM, and PLM).

The co-production of this socio-technical assemblage gives rise to the emergence of an ecosystem oriented towards digital servitization. In this case, the Ecomaq3.

The configuration of the **Ecomaq3** (Figure 4) is established with three main actors: **MAQ3,** which provides the routine system of machinery production, its techno-productive capacities, and agronomic and market knowledge. **AGT3.1** is a national Agtech company founded in 2012 that provides MAQ3 with a system–a digital platform for monitoring and control of harvesting machinery based on an IoT solution that captures data in real-time[13]. It then transforms them into information based on algorithms and programs and makes them available to the operator through a digital platform adapted exclusively for[14] MAQ3 customers for decision-making. AND **AGT3.2.** is a company with a long history in developing electronics and precision agriculture technologies, and it recently inaugurated an R+D division aimed at digital transformation.

The technological solution of the **Ecomaq3** implied a governance structure of the formalized co-production processes and permanent interaction dynamics led by the product development departments of MAQ3 and AGT3.1, including the customers and AGT3.2[15], with precision agroparts. On a technological level, the actors involved are working on updating and developing new STMaq3 functionalities. The latter implies new learning and interactions with R+D areas.

The co-production process around the STMaq3 is developing incremental innovations geared towards greater digital servitization. This drives routines of innovation and co-construction of knowledge in the different actors. MAQ3 orients its innovation strategies towards advancing autonomous (robotic) equipment, developing mechanisms in the agricultural machine to incorporate artificial intelligence in the future. Currently, they are exploring possibilities for joint developments with AGT3.2 and other potential players in computer vision and machine learning. On the other hand, AGT3.1. It links up with research centers[16] to optimize the monitoring system and automate the harvest solution as much as possible.

---

[13] Data captured from climate information systems (temperature, humidity, wind speed and direction), geopositioning, and machinery sensors that allow monitoring and controlling variables such as crop yield, grain moisture, path analysis, engine rpm, among others.

[14] The solution is factory-installed and from the second year onwards customers must pay an annual licence fee (AGT3) to maintain the accompanying services provided by the system.

[15] Punctually for the development of the solution in the trial phase of extraction and communication of agronomic data of the yield monitor.

[16] It has links with the Center for Research on Computational Methods (CIMEC, CONICET-UNL).

Figure 4. Ecomaq3 emergency

4.4. Similarities and differences in ecosystem DSI processes.

If we consider the common aspects of the analysis of the cases, we find patterns in the DSI processes of the emerging ecosystems. The redefinition of business strategy and business model is an emerging property of a system-actor dynamic driven by the socio-technical transition. In other words, there is co-evolution between the path dependence of machinery companies oriented towards DSI, the changes in the technological regime, the emergence of new technological niche firms (e.g., Agtech), and the socio-technical landscape oriented towards precision agriculture and sustainability.

Changing routines for providing intelligent services in machinery firms involved deliberation and interpretative flexibility with users and suppliers initially and then with other relevant actors such as Agtech. The service provision routines were not interrupted, but rather, based on their performativity (practices), significant adjustments and changes were made to the ostensive dimension (rules, norms, protocols) and vice versa. There are no meta-routines as in the classical evolutionary sense of innovation. The DSI is more in line with the Routine Dynamics perspective, where innovation is a continuum in the making.

The nature of the digital artifacts in changing service provision routines is crucial to the DSI dynamics of the three cases. In all cases, they exert agency over human behaviors (e.g., changes in the routines of machine users), but simultaneously, they are configurable and flexible enough to adapt to the requirements of designers and users. At the same time, in all cases, they exert socio-technical materiality effects that keep the ecosystem actors together. Here, the emergence of a socio-technical assemblage can be observed in each analyzed ecosystem (see Table 3). In all three socio-technical assemblage cases, the DSI process involved co-production, a technological solution oriented to the digital servitization of machinery and equipment. In all cases, this DSI process was driven by co-production between different actors and heterogeneous artifacts (digital and non-digital). This resulted in socio-technical assemblages. The provision of advanced services cannot be considered a phenomenon independent of technological innovation but an emergence of the socio-technical assemblage. New properties such as service provision routines, artifacts (platforms), and ecosystems oriented to digital servitization emerge from the DSI process of the three cases.

There is an ontology of these DSI processes that can be understood in terms of socio-technical assemblages, where humans and artifacts exert agency and feedback effects on each other. The convergence and alignment between the components of the socio-technical assemblage is not total. Firms providing knowledge to develop advanced services for digitization and platform development interact with other firms and institutions and can open and generate new socio-technical assemblages (e.g., biotech firms). Here, there is competitive bidding at the firm and ecosystem levels. In other words, technological solutions and DSI ecosystems compete. In short, there is competition between distributed cognition systems involving knowledge, skills, routine execution modalities, and automated processes, among other organizational phenomena.

Considering the differences in each biography analyzed, we can find specificities in the trajectories. The most significant of these is the specificity of the situated action where the co-production processes of technological solutions are generated and their relationship with path dependence effects. Although the process of emergence, development, and maturity of the analyzed ecosystems could be stylized as a typical pattern, if we consider the biography with greater granularity from a micro-organizational perspective, DSI processes involve uncertainty, imperfect information, experimentation, trial-and-error processes, iterations, convergence and ruptures between actors and technologies, as well as learning and unlearning processes. In other words, reversibility and irreversibility affect the convergence and alignment of the actors and artifacts involved in ecosystems.

Another issue distinguishing each trajectory is the configuration of distributed cognition systems and assemblages specific to each situated action, application domain, and trajectory of each firm. Here, the specificity of each trajectory of the emergence of the analyzed ecosystems evidences an underlying issue: the role of platforming as a process of convergence and progressive alignment of assemblages.

Table 3. Comparison of dimensions of socio-technical assemblages

5. Discussion.

Different issues emerge from the analysis of the case biographies, which must be discussed to answer our research questions. First, service and technological innovation in the current socio-technical transition towards digital servitization cannot be understood as independent entities. In this sense, the critique outlined by authors of the DSI perspective on the need to understand in-service innovation as part of the flow of contemporary technological innovation processes is evidenced (Opazo Basáez et al., 2024; Opazo-Basáez et al., 2021).

Second, based on the multidisciplinarity of DSI studies, Routine Dynamics (D'Adderio, 2011; Feldman et al., 2021; Feldman & Pentland, 2003) and sociomateriality (D'Adderio, 2021; Kallinikos et al., 2013; Leonardi et al., 2012) allow the consideration of concepts such as co-production, translation, interpretive flexibility, and socio-technical assemblages at the micro-organizational level of analysis. Simultaneously, the conceptual approach gives importance and centrality to the role of digital artifacts and their relationship with the change in innovation routines of manufacturing firms oriented toward DSI processes. Considering our RQ1, our findings show that there is a transition from the traditional visions of innovation routines (Deken & Sele, 2021), the transfer and replication of technologies in a solitary and unidirectional way (D'Adderio, 2014; Feldman et al., 2019) toward co-production processes between different actors. This conception of DSI processes understood in terms of co-production between humans and artifacts sheds light on the idea of co-innovation (Narvaiza et al., 2023) and co-design (Sjödin et al., 2020) that specific authors in the DSI literature tradition have proposed.

DSI is an emergent property that shows symmetry between actors (firms, institutions, users), routines, and digital artifacts. Thus, the DSI perspective, understood as the co-production of socio-technical assemblages, calls for a reinterpretation of traditional technological and service innovation processes towards a network and ecosystem perspective that highlights the ontology of digital artifacts. The nature of digital artifacts exerts agency over DSI practices and routines. These socio-technical and material dimensions (D'Adderio, 2021) also contribute to the analysis that scholars related to DSI have developed (Kapoor et al., 2022; Münch et al., 2022; Pelli & Lähtinen, 2020).

Our analysis of agribusiness ecosystem biographies shows, at the micro-level, that DSI processes involve co-production between routines, actors, and artifacts. This co-production implies moving from technology transfer relationships between manufacturers to the co-production of technological solutions oriented to digital servitization. New actors (Agtehc), digital and algorithmic artifacts, and changes in user practices emerge as translators, intermediaries, and drivers of DSI processes toward digital servitization and service platforms. Thus, the patterns of the configuration of networks of humans and artifacts that the social studies of technology have explored concerning the concept of translation and interpretative flexibility (Akrich et al., 2002;

Callon et al., 2002; Latour, 2007) offer conceptual aspects aimed at understanding the processes of DSI in terms of complexity and emergent properties (Opazo-Basáez et al., 2021; Rabetino et al., 2024). From the enrolment and interest of the actors, the debates, and tensions to define the functionality of technological solutions aimed at digital servitization, and the convergence of actors and artifacts and the co-creation of an assemblage guided by common business, technological, and innovation strategies are relevant to deepen analytically.

Third, the role of digital service platforms and users is critical in co-production and replicating technological solutions. Digital artifacts based on algorithmic technologies perform automation and augmentation routines (Raisch & Krakowski, 2021). The former relates to automated processes with less human involvement and expands human cognitive capabilities. In turn, they co-create value based on the services of digital platforms with machinery and equipment (RQ2). Here, users' progressive adoption of these digital artifacts is critical in achieving competitive positioning in the ecosystems and innovation of services based on algorithmic technologies (Johnson et al., 2022). Co-production ranges from digitizing traditional manufacturing artifacts and incorporating digital technologies oriented towards 'platformisation' to the permanent integration of technological solutions based on large databases and images with artificial intelligence software (Hein et al., 2020; Kohtamäki et al., 2022; Ritter & Pedersen, 2020).

6. Conclusions

6.1 Conceptual contribution

The study provides a complementary viewpoint between DSI approaches and the literature on Routine Dynamics and Sociomateriality. It explains in a micro-founded perspective, and based on biographies of the emergence of DSI ecosystems, how the relationship between artifacts based on algorithmic technologies, human practices, and routines in firms and organizations become dynamic in the co-production of Smart Solutions. This perspective proposes that DSI processes are based on the co-production of socio-technical assemblages. Thus, sociomateriality is at the center of analyzing the role of artifacts and the networks of relationships they perform and configure with humans, generating strategies, organizational practices, and heterogeneous routine dynamics. The configuration of socio-technical assemblages co-evolves with trends in the socio-technical transitions of manufacturing and services according to each industry.

6.2 Managerial and Policy Implications

The study has implications for managers involved in DSI processes.

- It is critical to analyze the dynamics of technological niches and scenarios to identify new business opportunities opened up by socio-technical transitions. In the case of agricultural machinery, the opportunities arising from digital servitization, precision agriculture, and sustainability are sources of innovation (Geels, 2010; Kohtamäki et al., 2022).
- Driving business strategies based on DSI processes is not limited to internal R&D efforts and/or incorporating digital technologies in manufacturing. It requires managing socio-technical assemblies that operate at the level of new technological solutions with digital and non-digital artifacts and routine changes in firms and users, where automation and augmentation of human skills continuously increase. It is crucial in developing precision agriculture 4.0 and sustainable agribusiness models in agricultural machinery.
- The technological solutions that emerge from DIS processes involve managing ecosystems that require experimental, open innovation models with permanent feedback

between production routines, service provision, and development of digital technologies (e.g., AI, Big Data, digital platforms).

- The context of the socio-technical transition towards Ag 4.0 and sustainability implies processes of strong competition between DSI-oriented ecosystems based on algorithmic technologies and the incorporation of users into digital service platforms. Incorporating users into data-driven and practice-oriented communities is crucial to connecting value creation with their growing demands for precision agriculture and sustainability (Hofmeister et al., 2023).

Concerning proposals for innovation policies, it is essential to:

- Promote public and private instruments and resources that encourage entrepreneurial development and R&D to take advantage of technological niches oriented to precision agriculture and digital servitization in machinery and equipment.
- Strengthen institutional frameworks where the agricultural machinery sector enhances cooperation with Agtech startups and other institutional actors (R&D institutions, universities). These institutional frameworks should aim to dynamize and consolidate DSI-oriented ecosystems.
- Promote university and technological education programs to train people with skills integrating digital transformation, innovation management, sustainability, and precision agriculture.

6.3 Limitations and opportunities for future research.

Regarding the limitations of the research, we recognize that its scope cannot be generalized in statistical terms but only as a conceptual contribution (Yin, 2013). Then, the specificity of the Argentine economy and its agricultural sector allows the development of this technological solution oriented to digital servitization for precision agriculture and sustainability. The scale of production will enable ecosystems with a large number and heterogeneity of players, national companies with a long history in machinery and equipment for precision agriculture, Agtech ventures, and multinational machinery and equipment companies such as John Deere, New Holland, and Class, among others. In turn, the sociotechnical transition is still in a moment of emergence, and it is expected that the biography of the trajectory of these ecosystems will require, in the short term, interviewing other relevant actors in the DSI process. Hence, it is essential to use biographical studies in the "in the making" style of actor-network theory.

Some ideas for further research are the following ones. First, we consider that the Routine Dynamics and sociomateriality approaches linked to the evolutionary tradition in economics and the social studies of technology can be new theoretical contributions to DSI studies. In particular, to highlight the relationship between technological innovation and innovation in services called for by the DSI agenda. (Opazo Basáez et al., 2024). Biographical studies can contribute to deepening the analysis of "digital service innovation" processes and practices with greater granularity, considering symmetrical relations between actors and digital artifacts. Studying trajectories and co-production processes would allow us to understand the complex, relational, and generative relationship between routines, digital artifacts, and advanced services (Rabetino et al., 2024). Finally, it will explore new questions related to the perspective of sociomateriality in studies. Fundamental could be to answer the following questions:

- How does the ontological ambivalence of digital artifacts (openness to interaction-fixed performances) condition service innovation processes? And how does this ambivalence mediate modalities of value capture and value generation?
- How do the design (or co-production) and affordances of digital artifacts 'perform' user practices for users to contribute to service innovation processes?

- How can the properties of digital artifacts (editability, openness, transfigurability, distributability, interactivity) enable, drive, or block service innovation processes?
- If we understand digital artifacts (e.g., an AI-based technological solution) as shaping materialities based on socio-technical assemblages, to what extent do they mediate service innovations based on automation and augmentation processes?

References

Abbasi, R., Martinez, P., & Ahmad, R. (2022). The digitization of agricultural industry – a systematic literature review on agriculture 4.0. Smart Agricultural Technology, 2, 100042. https://doi.org/10.1016/j.atech.2022.100042

Akrich, M., Callon, M., Latour, B., & Monaghan, A. (2002). The key to success in innovation part i: The art of interessement. International Journal of Innovation Management, 06(02), 187-206. https://doi.org/10.1142/S1363919602000550

Alaimo, C., & Kallinikos, J. (2024). Data rules: Reinventing the market economy. MIT Press.

Alvesson, M., & Sandberg, J. (2013). Has Management Studies Lost Its Way? Ideas for More Imaginative and Innovative Research. Journal of Management Studies, 50(1), 128-152. https://doi.org/10.1111/j.1467-6486.2012.01070.x

Annarelli, A., Battistella, C., Nonino, F., Parida, V., & Pessot, E. (2021). Literature review on digitalization capabilities: Co-citation analysis of antecedents, conceptualization and consequences. Technological Forecasting and Social Change, 166, 120635. https://doi.org/10.1016/j.techfore.2021.120635

Bijker, W. E. (2010). How is technology made?—That is the question! Cambridge Journal of Economics, 34(1), 63-76. https://doi.org/10.1093/cje/bep068

Bijker, W. E., Hughes, T. P., Pinch, T., & Douglas, D. G. (2012). The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology. MIT Press.

Bockshecker, A., Hackstein, S., & Baumöl, U. (2018). Systematization of the term digital transformation and its phenomena from a socio-technical perspective – A literature review. Research Papers. https://aisel.aisnet.org/ecis2018_rp/43

Bustinza, O. F., Gomes, E., Vendrell-Herrero, F., & Tarba, S. Y. (2018). An organizational change framework for digital servitization: Evidence from the Veneto region. Strategic Change, 27(2), 111-119. https://doi.org/10.1002/jsc.2186

Callon, M. (1987). Society in the Making: The Study of Technology as a Tool for Sociological Analysis. En W. E. Bijker, T. Hughes, & T. Pinch (Eds.), The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology (MIT Press, pp. 83-103).

Callon, M. (1990). Techno-economic Networks and Irreversibility. The Sociological Review, 38(1_suppl), 132-161. https://doi.org/10.1111/j.1467-954X.1990.tb03351.x

Callon, M. (2004). The role of hybrid communities and socio-technical arrangements in the participatory design. Journal of the Center for Information Studies.

Callon, M., Méadel, C., & Rabeharisoa, V. (2002). The economy of qualities. Economy and Society, 31(2), 194-217. https://doi.org/10.1080/03085140220123126

Cenamor, J., Parida, V., & Wincent, J. (2019). How entrepreneurial SMEs compete through digital platforms: The roles of digital platform capability, network capability and ambidexterity. Journal of Business Research, 100, 196-206.

Clarke, V., & Braun, V. (2017). Thematic analysis. The Journal of Positive Psychology, 12(3), 297-298. https://doi.org/10.1080/17439760.2016.1262613

Coreynen, W., Matthyssens, P., Vanderstraeten, J., & van Witteloostuijn, A. (2020). Unravelling the internal and external drivers of digital servitization: A dynamic capabilities and contingency perspective on firm strategy. Industrial Marketing Management, 89, 265-277.

D'Adderio, L. (2011). Artifacts at the centre of routines: Performing the material turn in routines theory. Journal of Institutional Economics, 7(2), 197-230. https://doi.org/10.1017/S174413741000024X

D'Adderio, L. (2014). The Replication Dilemma Unravelled: How Organizations Enact Multiple Goals in Routine Transfer. Organization Science, 25(5), 1325-1350. https://doi.org/10.1287/orsc.2014.0913

D'Adderio, L. (2021). Materiality and Routine Dynamics. In M. S. Feldman, B. T. Pentland, L. D'Adderio, K. Dittrich, C. Rerup, & D. Seidl (Eds.), Cambridge Handbook of Routine Dynamics (pp. 85–100). chapter, Cambridge: Cambridge University Press.

Deken, F., Carlile, P. R., Berends, H., & Lauche, K. (2016). Generating Novelty Through Interdependent Routines: A Process Model of Routine Work. Organization Science, 27(3), 659-677. https://doi.org/10.1287/orsc.2016.1051

Deken, F., & Sele, K. (2021). Innovation Work and Routine Dynamics. In M. S. Feldman, B. T. Pentland, L. D'Adderio, K. Dittrich, C. Rerup, & D. Seidl (Eds.), Cambridge Handbook of Routine Dynamics (pp. 288-300). Cambridge University Press. https://doi.org/10.1017/9781108993340.025

Deken, F., & Sele, K. (2021). Innovation Work and Routine Dynamics. Cambridge Handbook of Routine Dynamics; Cambridge University Press. https://doi.org/10.1017/9781108993340.025

Eisenhardt, K. M. (1989). Building Theories from Case Study Research. Academy of Management Review, 14(4), 532-550. https://doi.org/10.5465/amr.1989.4308385

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory Building From Cases: Opportunities And Challenges. Academy of Management Journal, 50(1), 25-32. https://doi.org/10.5465/amj.2007.24160888

Feldman, M. S. (2000). Organizational Routines as a Source of Continuous Change. Organization Science, 11(6), 611-629. https://doi.org/10.1287/orsc.11.6.611.12529

Feldman, M. S., D'Adderio, L., Dittrich, K., & Jarzabkowski, P. (2019). Routine Dynamics in Action: Replication and Transformation. Emerald Group Publishing.

Feldman, M. S., & Pentland, B. T. (2003). Reconceptualizing Organizational Routines as a Source of Flexibility and Change. Administrative Science Quarterly, 48(1), 94-118. https://doi.org/10.2307/3556620

Feldman, M. S., Pentland, B. T., D'Adderio, L., Dittrich, K., Rerup, C., & Seidl, D. (Eds.). (2021). Cambridge Handbook of Routine Dynamics. Cambridge University Press. https://doi.org/10.1017/9781108993340

Feldman, M. S., Pentland, B. T., D'Adderio, L., & Lazaric, N. (2016). Beyond Routines as Things: Introduction to the Special Issue on Routine Dynamics. Organization Science, 27(3), 505-513. https://doi.org/10.1287/orsc.2016.1070

Gebauer, H., Paiola, M., Saccani, N., & Rapaccini, M. (2020). Digital servitization: Crossing the perspectives of digitization and servitization. Industrial Marketing Management. https://doi.org/10.1016/j.indmarman.2020.05.011

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. Research Policy, 33(6), 897-920. https://doi.org/10.1016/j.respol.2004.01.015

Geels, F. W. (2020). Micro-foundations of the multi-level perspective on socio-technical transitions: Developing a multi-dimensional model of agency through crossovers between social constructivism, evolutionary economics and neo-institutional theory. Technological Forecasting and Social Change, 152, 119894. https://doi.org/10.1016/j.techfore.2019.119894

Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2013). Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology. Organizational Research Methods, 16(1), 15-31. https://doi.org/10.1177/1094428112452151

Glaser, B. G., & Strauss, A. L. (2017). Discovery of Grounded Theory: Strategies for Qualitative Research. Routledge.

Glaser, V. L., Pollock, N., & D'Adderio, L. (2021). The Biography of an Algorithm: Performing algorithmic technologies in organizations. Organization Theory, 2(2), 26317877211004609. https://doi.org/10.1177/26317877211004609

Golafshani, N. (2003). Understanding Reliability and Validity in Qualitative Research. The Qualitative Report, 8(4), 597-606. https://doi.org/10.46743/2160-3715/2003.1870

Greckhamer, T., Furnari, S., Fiss, P. C., & Aguilera, R. V. (2018). Studying configurations with qualitative comparative analysis: Best practices in strategy and organization research. Strategic Organization, 16(4), 482-495. https://doi.org/10.1177/1476127018786487

Hein, A., Schreieck, M., Riasanow, T., Setzke, D. S., Wiesche, M., Böhm, M., & Krcmar, H. (2020). Digital platform ecosystems. Electronic Markets, 30(1), 87-98. https://doi.org/10.1007/s12525-019-00377-4

Hinings, B., Gegenhuber, T., & Greenwood, R. (2018). Digital innovation and transformation: An institutional perspective. Information and Organization, 28(1), 52-61. https://doi.org/10.1016/j.infoandorg.2018.02.004

Huikkola, T., Rabetino, R., Kohtamäki, M., & Gebauer, H. (2020). Firm boundaries in servitization: Interplay and repositioning practices. Industrial Marketing Management, 90, 90-105. https://doi.org/10.1016/j.indmarman.2020.06.014

Hutchins, E. (2006). The Distributed Cognition Perspective on Human Interaction. En Roots of Human Sociality. Routledge.

Javaid, M., Haleem, A., Singh, R. P., & Suman, R. (2022). Enhancing smart farming through the applications of Agriculture 4.0 technologies. International Journal of Intelligent Networks, 3, 150-164. https://doi.org/10.1016/j.ijin.2022.09.004

Johnson, P. C., Laurell, C., Ots, M., & Sandström, C. (2022). Digital innovation and the effects of artificial intelligence on firms' research and development – Automation or augmentation, exploration or exploitation? Technological Forecasting and Social Change, 179, 121636. https://doi.org/10.1016/j.techfore.2022.121636

Kallinikos, J. (2011). Governing Through Technology: Information Artefacts and Social Practice. Palgrave Macmillan UK. https://doi.org/10.1057/9780230295148

Kallinikos, J., Aaltonen, A., & Marton, A. (2013). The Ambivalent Ontology of Digital Artifacts. MIS Quarterly, 37(2), 357–370. http://www.jstor.org/stable/43825913

Kapoor, K., Bigdeli, A. Z., Schroeder, A., & Baines, T. (2022). A platform ecosystem view of servitization in manufacturing. Technovation, 118, 102248. https://doi.org/10.1016/j.technovation.2021.102248

Kohtamäki, M., Parida, V., Oghazi, P., Gebauer, H., & Baines, T. (2019). Digital servitization business models in ecosystems: A theory of the firm. Journal of Business Research, 104, 380-392. https://doi.org/10.1016/j.jbusres.2019.06.027

Kohtamäki, M., Parida, V., Patel, P. C., & Gebauer, H. (2020). The relationship between digitalization and servitization: The role of servitization in capturing the financial potential of digitalization. Technological Forecasting and Social Change, 151, 119804. https://doi.org/10.1016/j.techfore.2019.119804

Kohtamäki, M., Rabetino, R., Parida, V., Sjödin, D., & Henneberg, S. (2022). Managing digital servitization toward smart solutions: Framing the connections between technologies, business models, and ecosystems. Industrial Marketing Management, 105, 253-267. https://doi.org/10.1016/j.indmarman.2022.06.010

Kowalkowski, C., & Witell, L. (2020). Typologies and frameworks in service innovation. In The Routledge Handbook of Service Research Insights and Ideas. Routledge.

Latour, B. (2007). Reassembling the Social: An Introduction to Actor-Network-Theory. OUP Oxford.

Lenka, S., Parida, V., & Wincent, J. (2017). Digitalization Capabilities as Enablers of Value Co-Creation in Servitizing Firms. Psychology & Marketing, 34(1), 92-100. https://doi.org/10.1002/mar.20975

Leonardi, P. M., Nardi, B. A., & Kallinikos, J. (2012). Materiality and Organizing: Social Interaction in a Technological World. OUP Oxford.

Lepratte, L., & Yoguel, G. (2023). Artefacts, routines, and co-production: A pioneering case of artificial intelligence-based health services in Argentina. Industry and Innovation, 0(0), 1-23. https://doi.org/10.1080/13662716.2023.2194241

Linde, L., Sjödin, D., Parida, V., & Gebauer, H. (2020). Evaluation of Digital Business Model Opportunities: A Framework for Avoiding Digitalization Traps. Research-Technology Management, 64(1), 43-53. https://doi.org/10.1080/08956308.2021.1842664

Münch, C., Marx, E., Benz, L., Hartmann, E., & Matzner, M. (2022). Capabilities of digital servitization: Evidence from the socio-technical systems theory. Technological Forecasting and Social Change, 176, 121361. https://doi.org/10.1016/j.techfore.2021.121361

Nag, R., Corley, K. G., & Gioia, D. A. (2007). The Intersection of Organizational Identity, Knowledge, and Practice: Attempting Strategic Change Via Knowledge Grafting. Academy of Management Journal, 50(4), 821-847. https://doi.org/10.5465/amj.2007.26279173

Nelson, R. R., & Winter, S. G. (1982). An Evolutionary Theory of Economic Change. Harvard University Press.

Opazo Basáez, M., Vendrell-Herrero, F., Bustinza, O. F., & Raddats, C. (2024). Guest editorial: Digital service innovation: ontology, context and theory. Journal of Service Management, 35(2), 129-140. https://doi.org/10.1108/JOSM-03-2024-498

Opazo-Basáez, M., Vendrell-Herrero, F., & Bustinza, O. F. (2021). Digital service innovation: A paradigm shift in technological innovation. Journal of Service Management, 33(1), 97-120. https://doi.org/10.1108/JOSM-11-2020-0427

Oudshoorn, N., & Pinch, T. (2013). How users matter: The co-construction of users and technology (inside technology). MIT Press.

Paiola, M., Agostini, L., Grandinetti, R., & Nosella, A. (2022). The process of business model innovation driven by IoT: Exploring the case of incumbent SMEs. Industrial Marketing Management, 103, 30-46. https://doi.org/10.1016/j.indmarman.2022.03.006

Parida, V., Sjödin, D., & Reim, W. (2019). Reviewing Literature on Digitalization, Business Model Innovation, and Sustainable Industry: Past Achievements and Future Promises. Sustainability, 11(2), Article 2. https://doi.org/10.3390/su11020391

Parmentier-Cajaiba, A., Lazaric, N., & Cajaiba-Santana, G. (2021). The effortful process of routines emergence: The interplay of entrepreneurial actions and artefacts. Journal of Evolutionary Economics, 31(1), 33-63. https://doi.org/10.1007/s00191-020-00691-7

Pelli, P., & Lähtinen, K. (2020). Servitization and bioeconomy transitions: Insights on prefabricated wooden elements supply networks. Journal of Cleaner Production, 244, 118711. https://doi.org/10.1016/j.jclepro.2019.118711

Pinch, T. (2008). Technology and institutions: Living in a material world. Theory and Society, 37(5), 461-483. https://doi.org/10.1007/s11186-008-9069-x

Rabetino, R., Harmsen, W., Kohtamäki, M., & Sihvonen, J. (2018). Structuring servitization-related research. International Journal of Operations & Production Management, 38(2), 350-371. https://doi.org/10.1108/IJOPM-03-2017-0175

Rabetino, R., Kohtamäki, M. and Huikkola, T. (2024), "Digital service innovation (DSI): a multidisciplinary (re)view of its origins and progress using bibliometric and text mining methods", Journal of Service Management, Vol. 35 No. 2, pp. 176-201. https://doi.org/10.1108/JOSM-12-2022-0375

Raddats, C., Naik, P., & Ziaee Bigdeli, A. (2022). Creating value in servitization through digital service innovations. Industrial Marketing Management, 104, 1-13. https://doi.org/10.1016/j.indmarman.2022.04.002

Raisch, S., & Krakowski, S. (2021). Artificial Intelligence and Management: The Automation–Augmentation Paradox. Academy of Management Review, 46(1), 192-210. https://doi.org/10.5465/amr.2018.0072

Ritter, T., & Pedersen, C. L. (2020). Digitization capability and the digitalization of business models in business-to-business firms: Past, present, and future. Industrial Marketing Management, 86, 180-190. https://doi.org/10.1016/j.indmarman.2019.11.019

Rodríguez, M. A., Lepratte, L., & Rabetino, R. (2021). Dynamic Capabilities as Enablers of Digital Servitization in Innovation Ecosystems: An Evolutionary Perspective. The Palgrave Handbook of Servitization, 181-195. https://doi.org/10.1007/978-3-030-75771-7_12

Rohlfing, I. (2012). Case Studies and Causal Inference. Palgrave Macmillan UK. https://doi.org/10.1057/9781137271327

Salvato, C., & Rerup, C. (2011). Beyond collective entities: Multi-level research on organizational routines and capabilities. Journal of Management, 37(2), 468-490.

Santos Valle, S., & Kienzle, J. (2020). Agriculture 4.0 – Agricultural robotics and automated equipment for sustainable crop production. https://policycommons.net/artifacts/1422028/agriculture-40/2036099/

Sjödin, D., Parida, V., Kohtamäki, M., & Wincent, J. (2020). An agile co-creation process for digital servitization: A micro-service innovation approach. Journal of Business Research. https://doi.org/10.1016/j.jbusres.2020.01.009

Sklyar, A., Kowalkowski, C., Tronvoll, B., & Sörhammar, D. (2019). Organizing for digital servitization: A service ecosystem perspective. Journal of Business Research, 104, 450-460. https://doi.org/10.1016/j.jbusres.2019.02.012

Smania, G. S., de Sousa Mendes, G. H., Godinho Filho, M., Osiro, L., Cauchick-Miguel, P. A., & Coreynen, W. (2022). The relationships between digitalization and ecosystem-related capabilities for service innovation in agricultural machinery manufacturers. *Journal of Cleaner Production*, *343*, 130982.

Stake, R. E. (1994). Case Study: Composition and Performance. Bulletin of the Council for Research in Music Education, 122, 31-44.

Suchman, L. A. (2007). Human-machine reconfigurations: Plans and situated actions. Cambridge University Press.

Vendrell-Herrero, F., Bustinza, O. F., Parry, G., & Georgantzis, N. (2017). Servitization, digitization and supply chain interdependency. Industrial Marketing Management, 60, 69-81. https://doi.org/10.1016/j.indmarman.2016.06.013

Warner, K. S. R., & Wäger, M. (2019). Building dynamic capabilities for digital transformation: An ongoing process of strategic renewal. Long Range Planning, 52(3), 326-349. https://doi.org/10.1016/j.lrp.2018.12.001

Yin, R. K. (2013). Case Study Research: Design and Methods. SAGE Publications.

Tables and Figures

Table 1. Cases analyzed and data collection structure

Cases	Ecosystem 1 (Ecomaq1)	Ecosystem 2 (Ecomaq2)	Ecosystem 3 (Ecomaq 3)
Core Technological Solution of the Ecosystem's machinery/equipment company	An integrated solution involving products (spraying machinery) and advanced services (digital platform with monitoring, control, and optimization system for phytosanitary applications) aimed at optimizing the customer's agricultural processes.	An integrated solution that involves products (fertilizing machinery) and advanced services (a digital platform with monitoring, control, and optimization systems for nutrient applications) to optimize agricultural processes and customer yields. Integration of the solution with UAV + computer vision	An integrated solution involving products (harvesting machinery) and advanced services (monitoring and control system of harvesting tasks) aimed at optimizing the customer's agricultural processes.
Actors	1.MAQ1: Precision Ag Product Marketing Manager 2.AGT1: CEO 3.BT1: Marketing manager IT service and consulting firm 4. Public Research institution (INTA-1): Coordinator of the Agricultural Mechanization Group	1.MAQ2: Marketing Manager 2.MAQ2: Agtech & robotics Manager 3.AGT2: CEO 4. University (UNIV-2): Agricultural Mechanization Research Group	1.MAQ3: R&D Manager 2.MAQ3: Commercial Manager 3.AGT3.1: CEO (AGT 1: CEO 4. Public Research institution (CIFASIS): Coordinator of Group of Research on Bioinformatics and Agroinformatics. 5.AGT3.2. CEO
Reconstructed Period of the Biography of the Technological Solution	2016 to 2022	2009 to 2022	2018 to 2023
Reconstructed Period of the Biography of the Technological Solution	Agricultural machinery; Agtech; IT Web Development Consultant; Dealers; Users; Science and Technology Institutions.	Agricultural machinery; Agtech; Users; Technology partners (AI in programming and investors); Science and technology institutions.	Agricultural machinery; Agtech; Users; Science and Technology Institutions, Agtech Precision Ag.
Agricultural machinery; Agtech; Users; Science and Technology Institutions, Agtech Precision Ag.	Sowing and spraying monitor. Controller and/or actuator devices for Spray Section Cutting System. Smart product applications[1]. Analysis engines and mathematical models (algorithms). Application Platform[2].	Sowing and spraying monitor. Controller and/or actuator devices for Spray Section Cutting System. Smart product applications[6]. Analysis engines and mathematical models (algorithms).	Harvest yield monitor. Smart product applications. Application Platform. Communication networks. Product software. Product hardware

[1] Software applications that run on remote servers and manage the monitoring, control, optimization, and autonomous operation of product functions.

[2] An application development and execution environment that enables the rapid creation of intelligent, connected business applications using data access, visualization, and execution tools.

[6] Software applications that run on remote servers and manage the monitoring, control, optimization, and autonomous operation of product functions.

	Communication networks[3]. Product software[4]. Product hardware[5]. Gateway to external information sources. Integration tools with business systems (ERP, CRM, and PLM).	Application Platform[7]. Communication networks[8]. Application Platform. Communication networks. Product software. Product hardware. Gateway to external information sources. Integration tools with business systems (ERP, CRM, and PLM). UAV (drone) and AI tools.	Application Platform[9]. Communication networks[10]. Application Platform. Communication networks. Product software. Product hardware. Gateway to external information sources. Integration tools with business systems (ERP, CRM, and PLM). UAV (drone) and AI tools.

[3] Protocols that enable communications between the product and the cloud.
[4] An integrated operating system, on-board software applications, an enhanced user interface, and product control components.
[5] Built-in sensors, processors, and a connectivity port/antenna complement traditional mechanical and electrical components.
[7] An application development and execution environment that enables the rapid creation of intelligent, connected business applications using data access, visualization, and execution tools.
[8] Protocols that enable communications between the product and the cloud.
[9] An application development and execution environment that enables the rapid creation of intelligent, connected business applications using data access, visualization, and execution tools.
[10] Protocols that enable communications between the product and the cloud.

Table 2. Distribution of interviews

Ecosystems (codification)	Firms (codification)	Actors interviewed (codification)	Number of interviews	Total duration (minutes)	Total Interviews
Ecosystem 1 (Ecomaq1)	Precision Agriculture Machinery (MAQ1)	Product Marketing Manager (PMM-Maq1)	1	60 minutes, approx.	4
	Agtech firm specialized agricultural processes (AGT1)	CEO (CEO-AGT1)	1	50 minutes, approx.	
	IT service and consulting firm (BT1)	Marketing manager (MM-Bt1)	1	45 minutes, approx.	
	Public Research Institution (INTA-1)	Coordinator of the Agricultural Mechanization Group (INTA-1)	1	40 minutes, approx.	
Ecosystem 2 (Ecomaq2)	Agriculture Machinery Firm (MAQ2)	Marketing Manager (MM-Maq2) Agtech & robotics Manager (AgRobotM-Maq2)	2	100 minutes, approx.	4
	Agtech Firm based on Artificial Intelligence (AGT2)	CEO (CEO-AGT2)	1	120 minutes, approx	
	University (UNIV-2)	Agricultural Mechanization Research Group	1	40 minutes, approx.	
Ecosystem 3 (Ecomaq3)	Agriculture Machinery Firm (MAQ3)	R&D Manager (R&DM-Maq3) Commercial Manager (MM-Maq3)	2	80 minutos, approx	4
	Agtech firm specialized agricultural processes (AGT3.1)	CEO (CEO-AGT3.1)	1	45 minutes, approx.	
	Public Research Institution (CIFASIS-3)	Coordinator of the Bioinformatics and Agroinformatics Research Group (Coord-cifasis-3)	1	80 minutes, approx	
	Agtech firm specialized agricultural processes (AGT3.2)	CEO (CEO-AGT3.2)	1	50 minutes, approx.	

Figure 1

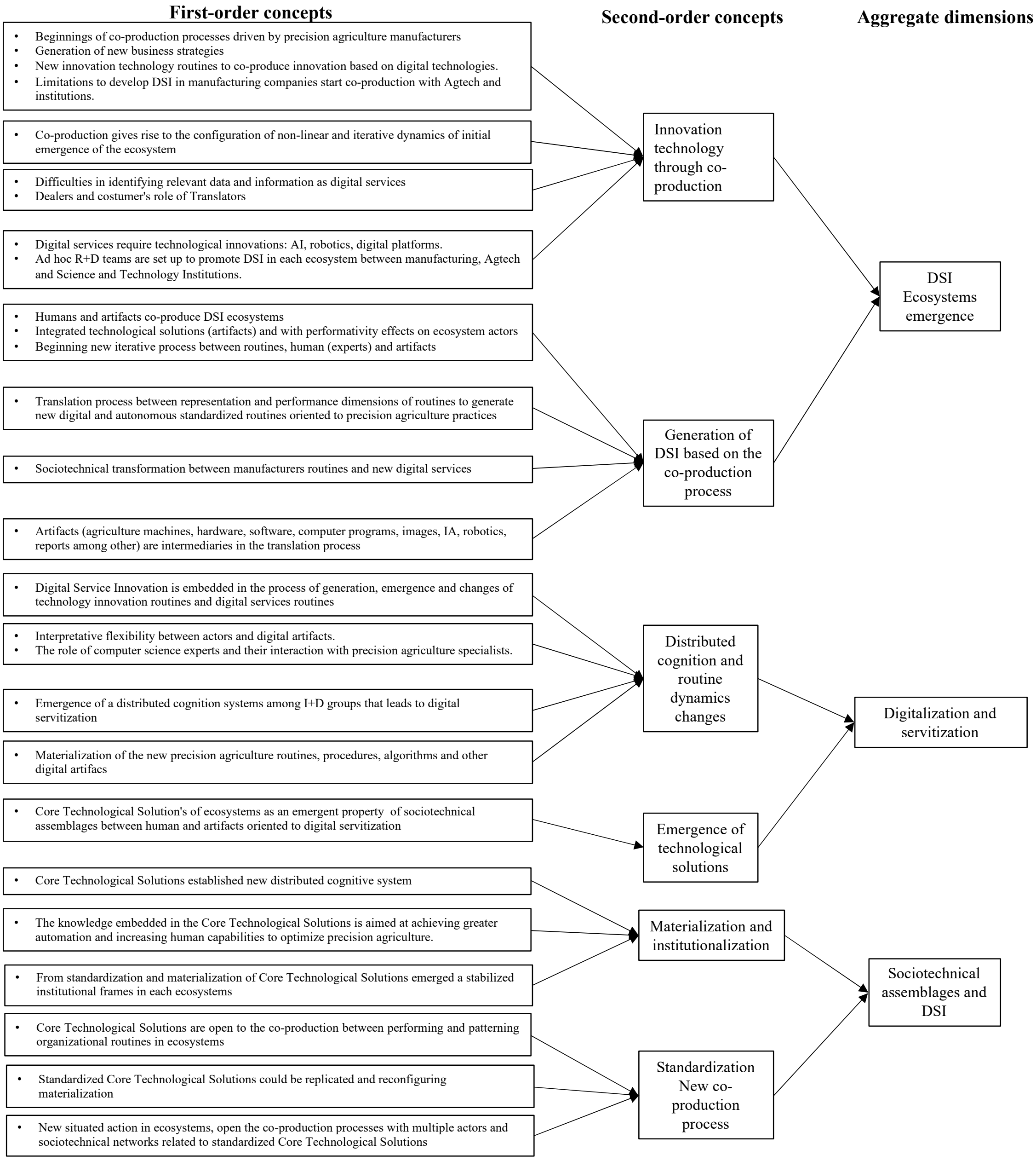

First-order concepts
Second-order concepts
Aggregate dimensions
• Beginnings of co-production processes driven by precision agriculture manufacturers
• Generation of new business strategies
• New innovation technology routines to co-produce innovation based on digital technologies.
• Limitations to develop DSI in manufacturing companies start co-production with Agtech and institutions.
• Co-production gives rise to the configuration of non-linear and iterative dynamics of initial emergence of the ecosystem
• Difficulties in identifying relevant data and information as digital services
• Dealers and costumer's role of Translators
• Digital services require technological innovations: AI, robotics, digital platforms.
• Ad hoc R+D teams are set up to promote DSI in each ecosystem between manufacturing, Agtech and Science and Technology Institutions.
• Humans and artifacts co-produce DSI ecosystems
• Integrated technological solutions (artifacts) and with performativity effects on ecosystem actors
• Beginning new iterative process between routines, human (experts) and artifacts
• Translation process between representation and performance dimensions of routines to generate new digital and autonomous standardized routines oriented to precision agriculture practices
• Sociotechnical transformation between manufacturers routines and new digital services
• Artifacts (agriculture machines, hardware, software, computer programs, images, IA, robotics, reports among other) are intermediaries in the translation process
• Digital Service Innovation is embedded in the process of generation, emergence and changes of technology innovation routines and digital services routines
• Interpretative flexibility between actors and digital artifacts.
• The role of computer science experts and their interaction with precision agriculture specialists.
• Emergence of a distributed cognition systems among I+D groups that leads to digital servitization
• Materialization of the new precision agriculture routines, procedures, algorithms and other digital artifacs
• Core Technological Solution's of ecosystems as an emergent property of sociotechnical assemblages between human and artifacts oriented to digital servitization
• Core Technological Solutions established new distributed cognitive system
• The knowledge embedded in the Core Technological Solutions is aimed at achieving greater automation and increasing human capabilities to optimize precision agriculture.
• From standardization and materialization of Core Technological Solutions emerged a stabilized institutional frames in each ecosystems
• Core Technological Solutions are open to the co-production between performing and patterning organizational routines in ecosystems
• Standardized Core Technological Solutions could be replicated and reconfiguring materialization
• New situated action in ecosystems, open the co-production processes with multiple actors and sociotechnical networks related to standardized Core Technological Solutions
Innovation technology through co-production
Generation of DSI based on the co-production process
Distributed cognition and routine dynamics changes
Emergence of technological solutions
Materialization and institutionalization
Standardization New co-production process
DSI Ecosystems emergence
Digitalization and servitization
Sociotechnical assemblages and DSI

Figure 2

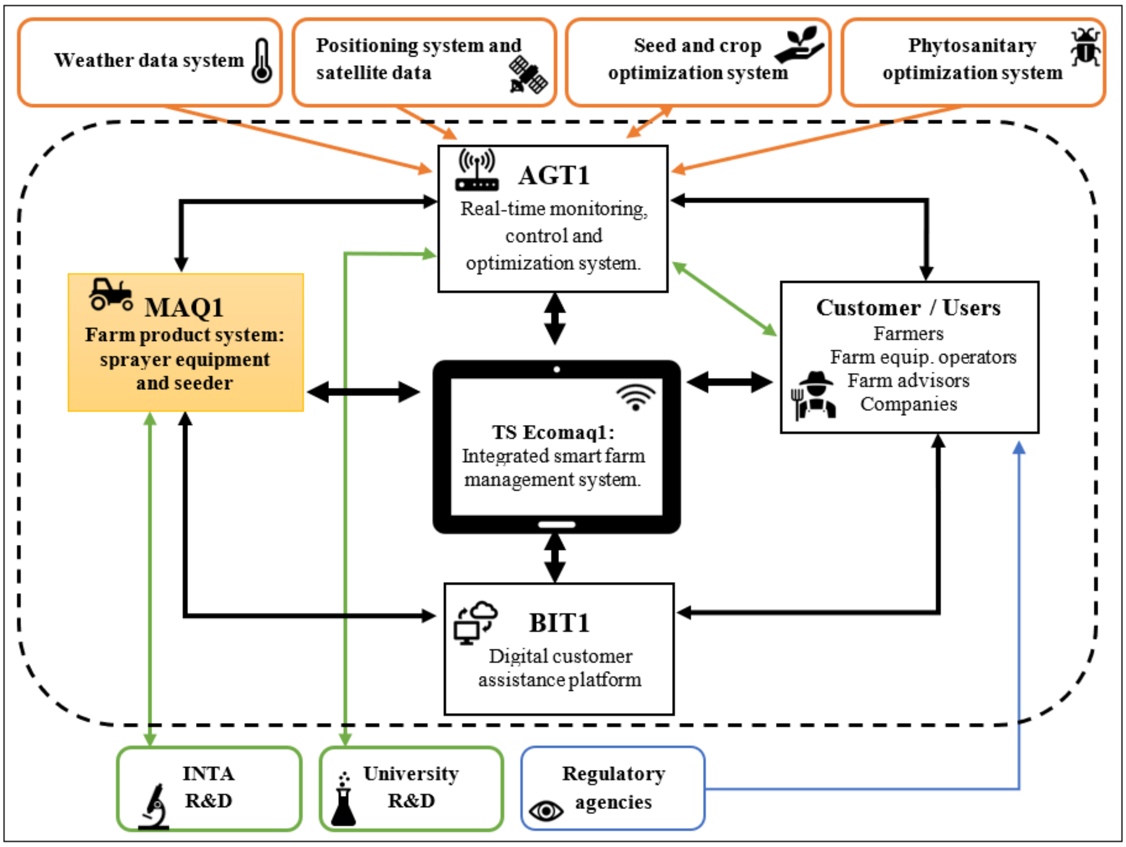


Figure 3

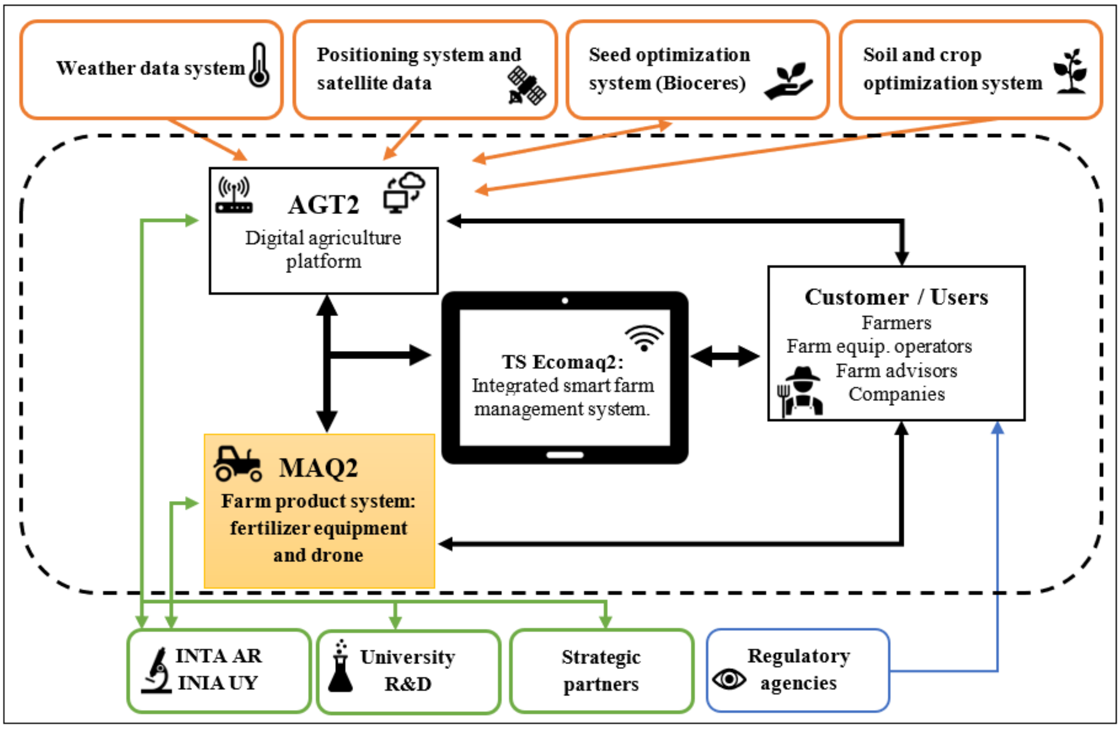
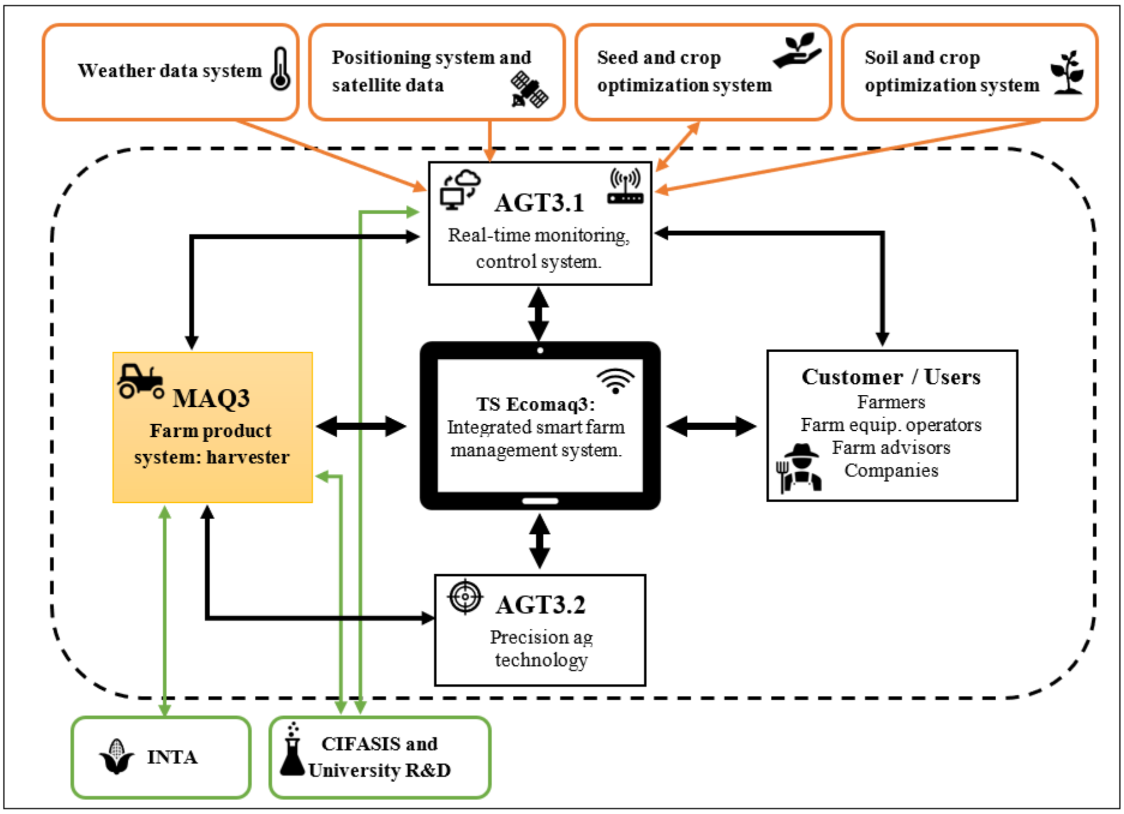


Figure 4



Weather data system
Positioning system and satellite data
Seed and crop optimization system
Soil and crop optimization system
AGT3.1
Real-time monitoring, control system.
MAQ3
Farm product system: harvester
TS Ecomaq3:
Integrated smart farm management system.
Customer / Users
Farmers
Farm equip. operators
Farm advisors
Companies
AGT3.2
Precision ag technology
INTA
CIFASIS and University R&D

Table 3. Comparision of dimensions of socio-technical assemblages.

Dimensions of Analysis	**Ecomaq1**	**Ecomaq2**	**Ecomaq3**
Digital Service Innovation (DSI) Processes	Co-production of technological solutions with actors such as Agtech firms and IT consultancy. Shift to remote and permanent monitoring for precision agriculture.	Co-production with AGT2, focused on integrating precision fertilizing machinery with AI-based digital platforms.	Focused on advanced harvesting solutions, integrating IoT and real-time monitoring. Transitioning to more autonomous, robotic machinery.
Relationships Between Actors and Artifacts	Collaboration with Agtech1 for IoT-based monitoring systems and BIT1 for customer digital platforms. Concessionaires also involved.	Strong collaboration with AGT2, which contributes AI, software expertise, and UAV technology. INTA and UNMdP provide validation and testing support.	Partnership with AGT3.1 for IoT-based monitoring systems and AGT3.2 for precision agriculture technology. External R&D centers provide additional support.
Changes in Organizational Routines	Adoption of new routines around digital servitization and product monitoring. Coupling electromechanical processes with digital innovation.	Creation of a new Agtech and Robotics department, incorporating digitalization capabilities and robotics expertise to drive innovation projects.	Creation of an Electronics Department to handle software and platform development. Exploration of AI for future autonomous machinery.
Distributed Cognition Systems	Real-time data monitoring, algorithms, digital platforms, and customer feedback loops.	AI-driven decision support systems for crop monitoring and nutrient management, based on UAV and computer vision.	Advanced real-time monitoring systems for harvest control. Potential expansion into autonomous machinery and robotic solutions.
Forms of Appropriation of Innovations	Knowledge co-creation with clients and partners, evolving products and services based on user feedback.	Innovations appropriated through collaboration with AI and robotics specialists. Focus on sustainability and efficiency in nutrient application.	Innovations appropriated through collaboration with national and international technology partners, targeting niche markets for autonomous systems.
User Practices	Transformation of machine users into participants in data-driven agriculture practices through real-time platforms.	Users engage in data-driven management, controlling and optimising fertilization with precision tools and platform feedback.	User practices shift towards remote control and digital management of harvesting operations.
Business Models	From product sales to service-oriented, offering integrated machinery and digital services.	Transition to advanced services like nutrient optimization through smart applications, competing against larger multinational firms.	Move towards offering integrated harvesting solutions with real-time control and monitoring, serving niche markets with advanced tech.
Governance of the Emerging Ecosystem	Led by MAQ1 with contributions from Agtech1 and BIT1. Continuous interactions between R&D, product development, and customers.	Governed by a formal Collaborative R&D Program between MAQ2 and AGT2, with involvement from academia for validation.	Governance shared between MAQ3 and its partners, with continuous interaction in R&D and product development, focusing on innovation.