Received: 8 March 2021 | Accepted: 21 February 2022

DOI: 10.1002/aepp.13246

FEATURED ARTICLE

The farm to fork strategy and the digital transformation of the agrifood sector—An assessment from the perspective of innovation systems

Tilman Reinhardt

Faculty of Life Sciences: Food, Nutrition and Health, University of Bayreuth, Kulmbach, Germany

Correspondence
Tilman Reinhardt, Faculty of Life Sciences: Food, Nutrition and Health, University of Bayreuth, Fritz-Hornschuch-Straße 13, 95326 Kulmbach, Germany.
Email: tilman.reinhardt@uni-bayreuth.de

Editor in charge: Kai Purnhagen

Abstract

The article assesses the European Union's Farm to Fork (F2F) strategy from the perspective of innovation systems, focusing on digital technologies in agriculture. It employs the Technical Innovation Systems framework to analyze how the policies proposed in the F2F strategy affect essential functions of the innovation system. The analysis shows that the F2F strategy significantly contributes to innovation system performance by providing a clear and coherent agenda and various concrete measures designed to support innovation, knowledge and skill development. However, the strategy falls short in creating favorable market conditions for innovative technologies and building legitimacy with farmers as the most important user group.

KEYWORDS

digital technologies in agriculture, farm to fork strategy, innovation systems

JEL CLASSIFICATION

Q18, O38, B52

The European Union (EU)'s Farm to Fork (F2F) strategy, launched in 2020, aims for a comprehensive sustainability transition of the European agrifood sector. However, as the strategy itself acknowledges and various impact assessments (Barreiro-Hurle et al., 2021; Beckman et al., 2020; Henning et al., 2021; Noleppa & Cartsburg, 2021) have shown, political will alone will not achieve its ambitious goals. Success heavily depends on innovation, both the scaling of existing innovations and the development of totally new innovations. This article seeks to assess, how the propositions of the F2F strategy affect the development and diffusion of innovations using the Technological Innovation Systems (TIS) framework. It focusses on digital technologies, which will be at the heart of future food systems and policies.

This first part describes the central role of digital technologies for achieving sustainability in the agrifood sector. The second part presents the TIS framework as a tool to assess innovation system performance and related policies. The third part applies the TIS framework to analyte seven core functions of the innovation system for digital technologies in the agrifood sector, describing key challenges and the policy responses given in the F2F strategy. The fourth part discusses the findings: It shows that the F2F strategy contributes to an "institutional alignment" in the innovation system by providing a clear agenda for transformation and proposing various innovation support measures. However, it falls short in tackling structural barriers to innovation and addressing the profound social implications of digitalization. Its "leave no one behind" approach is contrary to a Schumpeterian process of "creative destruction." The fifth part reaches tentative conclusions. The F2F strategy can be seen as a paradigm-changing mission statement for the sustainability transformation of the sector. To reach its goals, however, a much wider range of regulatory tools needs to be employed.

THE DIGITAL TRANSFORMATION OF THE AGRIFOOD SECTOR

The digital transformation, that is, the development and diffusion of digital, data-driven technologies, appears to be the essential backdrop against which the European agrifood sector will develop in the period until 2030: While some technologies have been around for decades, and diffusion has initially been slower than expectations (Weltzien, 2016), there now appears to be a renewed and self-sustaining push to digitalize all levels of the food value chain (Klerkx et al., 2019; Rose & Chilvers, 2018). This is evidenced by an accelerating pace of adoption (Shang et al., 2021), a growing interest in high-level policy documents (Lajoie-O'Malley et al., 2020) and the market entry of large outside players, such as Microsoft or IBM. Reasons for this recent dynamic are manifold: Technological maturity (Shamshiri et al., 2018), development of new business models on the supply (e.g., sharing economy [Mittermayr, 2020]) and the demand side (e-commerce, traceability, personalized food [Sozer, 2020]), as well as regulatory changes (e.g., documentation duties, fertilizing and pesticide limits, food safety, and traceability standards). The ongoing Covid pandemic acts as an additional catalyst.

The digital transformation, however, is not just an inevitable fact, it is also the "best hope" for achieving sustainability in food production (Basso & Antle, 2020). Digital technologies are seen as key solutions to bridge the gap between productivity and sustainability (El Bilali & Allahyari, 2018; Klerkx et al., 2019). Precision (livestock) farming technologies and data-driven decision-making tools based on Machine Learning or AI promise greater efficiency, but also a reduction of pesticides, fertilizers, antibiotics, and GHG emissions, as well as better protection of soils and biodiversity (Sharma et al., 2020). Integration of data in logistics and processing allows for completely new value opportunities, helps to reduce food waste and move toward an integrated food system (El Bilali & Allahyari, 2018; Zeb et al., 2021). In addition, digital technologies also hold great potential to tailor effective policy measures (Ehlers et al., 2021; Kosior, 2019a). Some potentially game-changing policy instruments, such as carbon sequestration (Lal et al., 2018), crucially depend on digital capacities to administer and control (cf. Fn. 10 of the F2F strategy).

Of course, digital technologies are no panacea for achieving sustainability (El Bilali & Allahyari, 2018). Their social and environmental implications are in many ways unclear and potentially dangerous (Klerkx & Rose, 2020). Achieving sustainability in the context of digital transformation therefore crucially depends on getting the policies right. Whether the F2F strategy is up for this challenge, is the main question of this article.

The article also does not argue that other innovations are irrelevant for the sustainability transformation of the food system. From nanotechnology to artificial meat and vertical farming, a lot of disruptive approaches may shape the image of Agriculture 4.0 and contribute to its sustainability (Klerkx & Rose, 2020). In particular, new plant breeding technologies (NPBTs) bear great potential for increasing productivity and minimizing environmental impact (Purnhagen & Wesseler, 2021; Qaim, 2020). Innovative feed, for example, insects or algae (*Asparagopsis*), bears the potential to reduce emissions related to animal production (Adegbeye et al., 2020).

The article focusses on digital technologies to analyze the F2F strategy's impact on innovation for two reasons: First, digital, data-driven technologies are a precondition for almost all other innovations. They can be seen as the ultimate "enabling technology" (Bigliardi et al., 2020). Second, for many other "game changers," especially biotechnology, the technological and regulatory discussion follows specific trajectories. In the F2F strategy, the EU evidently did not want to take concrete decisions, but rather communicate the values, objectives and instruments that will govern European food policy in the future.

MATERIALS AND METHODS

The central role of innovations for economic development has been recognized over 100 years ago in the seminal contribution of Schumpeter (1912). The process of creative destruction has since been integrated into standard endogenous growth models (Aghion & Howitt, 1992), giving rise to a wide literature on the effects of innovation on many areas of the economy (Akcigit & van Reenen, 2021). In particular, recent works show how public policies can redirect technological change toward sustainable technologies (Acemoglu et al., 2012).

FIGURE 1 Technological innovation system (TIS) framework according to Bergek et al. (2008b). *Source*: Own illustration [Color figure can be viewed at wileyonlinelibrary.com]

However, the growth models employed in this literature are usually quite general in their analysis of the innovation process and the conditions contributing to it. To this end, innovation systems research has developed as a field since the 1980s building on previous research in evolutionary economics (Greenacre et al., 2012). This research emphasizes the nonlinearity and complexity of economic processes and the coevolution of knowledge, organizational structures and institutions: The latter emerge as the central factor for development (Malerba & McKelvey, 2020) whereas "market failure" is rejected as a basis for policy action (Bergek et al., 2008b; Dolfsma & Leydesdorff, 2009). The focus of public policy is seen on strengthening firms' capacities to internalize knowledge and become part of an "innovation system," for example, through supporting R&D networks, strengthening intermediaries and incubators (Nilsson & Sia-Ljungström, 2013) as well as through resolving institutional lock-ins and path dependencies among incumbent firms and consumers (Cecere et al., 2014).

Since at least the 1990s, innovation systems thinking has also influenced policy making. A notable example can be seen in the European Innovation Partnership (EIP)-Agri, with its focus on the cocreation of innovations by multistakeholder groups (EU SCAR AKIS, 2019). The innovation systems approach however has not affected European agricultural policy in general.

One of the most common and accessible analytical frameworks for innovation systems is the TIS framework proposed by Bergek et al. (2008b) (Figure 1). It integrates insights from various disciplines and allows for straightforward inference of policy recommendations. It emphasizes the "functionality" of innovation systems, rather than their structures. The focus is on a specific technology or knowledge field, with scales ranging from "nested" to general and global innovation systems (Bergek et al., 2015). Hundreds of studies have used the TIS framework for analyzing technological development especially in the energy sector (Köhler et al., 2019).

More recently, innovation research has started to integrate with research on sustainability transformations (Köhler et al., 2019), analyzing "responsible" (Eastwood et al., 2019), "mission-oriented" (Hekkert et al., 2020), "dedicated" (Pyka et al., 2019), or "eco" innovation systems (Greenacre et al., 2012). These systems are characterized by strong directionality, high urgency and an even greater role for regulatory intervention (Cecere et al., 2014). Policy in such systems must not only address blocking mechanisms, but become itself a catalyst for innovation system performance (Nevzorova & Karakaya, 2020). So far, no clear analytical standard has emerged to capture all the dimensions of directionality (Hekkert et al., 2020; Lindner et al., 2016). In this article, the classical TIS framework is therefore applied, and aspects of directionality are discussed in the conclusions.

Description of the TIS approach

The TIS framework proposes a systematic step-by-step approach to analyze innovation systems and policies (Bergek et al., 2008b): The first step consists in defining the innovation system and mapping its main structural components, that is, actors, networks, and institutions. In the second step, its "functional dynamics" are analyzed, that is, seven processes seen as essential for the system's performance: Knowledge development and diffusion, guidance of search, entrepreneurial experimentation, market formation, legitimation, resource mobilization, and development of positive externalities. These functional dynamics are affected by technological properties but also social factors, such as beliefs or policies (Bergek et al., 2015). For every functional dynamic, a "desired" functional pattern is contrasted with actual performance to identify inducing or blocking mechanisms. These mechanisms can then be related to policy issues.

Depending on the concrete analytical interest, the framework allows for integration of quantitative and qualitative data as well as pure literature studies.

Application of the TIS framework to analyze the F2F strategy

Compared to its wide use in the energy sector, the TIS framework has seen less application in the agrifood sector. This might be due to the belated recognition of the need for a sustainability transformation in agriculture. Also, innovation research in agriculture employs specific analytical constructs such as agricultural or rural innovation systems. Given this article's goal of assessing the F2F strategy, which covers primary production as well as processing, marketing and even consumption, the TIS approach, however, seems more appropriate than specific analytical frameworks for agriculture. Data for the analysis is derived from recent scientific literature. Given the dynamic and industry-driven development of technology, the article also integrates gray literature, for example, presentations and statements in multistakeholder fora.

RESULTS

Definition of the TIS (technology, scale, and phase)

The *innovation system* in the TIS framework is not a real but an analytical construct, that is, a tool to illustrate and understand system dynamics and performance: Actors in the innovation system do not exist for that purpose or act consciously as part of a system (Bergek et al., 2008b). The focus of this analytical construct can be very narrow concentrating on a concrete technological application or very broad encompassing an entire knowledge field. In this article, the TIS framework is used to assess the F2F strategy, that is a high-level policy document with EU wide and even global ambition. The TIS is, therefore, defined broadly: It comprises smart-farming technologies, that is, software applications and corresponding hardware tools, such as variable rate technology, robotics, sensor systems, IoT or 5G technology, but also digital business models, such as sharing economy platforms, digital marketplaces or everything-as-a-service type applications as well as downstream applications in processing or logistics.

Technology development is global, with significant impulses coming from non-EU countries, for example, the United States, China, India, Australia, Russia, or Israel. Outside developments may significantly affect the Innovation System, although at the moment there is a knowledge gap regarding international developments, especially in BRICS countries (Klerkx et al., 2019).

Policy implications derived from TIS analysis significantly depend on the "phase" of the innovation system (Bergek et al., 2008a; Markard, 2020). Given the broad definition of the TIS, this is difficult to pinpoint. While it seems to have entered a self-sustaining growth phase for some products, large technological, economic and regulatory uncertainties remain. Overall, the TIS is therefore considered to still be in the "formative phase."

Mapping of structures

Given the broad scope of the analysis and the multifaceted European context, a detailed mapping of all structures in the innovation system is neither possible nor necessary. The focus of investigation lies on identifying key challenges concerning the functionality of the system. Actors, networks, and institutions are therefore described broadly and based on examples.

Actors

On the supply side, "big Ag" companies, such as John Deere, are key drivers of technology development (Rotz et al., 2019; van Es & Woodard, 2017). Given the complex technological challenges, they form new alliances among each other (cf. DataConnect), with actors from outside agriculture (cf. NEVONEX/Agrirouter) and with research institutions (Eastwood et al., 2017). In some cases, agritech companies start to act as service providers (e.g., the xarvio brand by BASF). Start-ups play an increasing role, notably in the fields of software and field robotics (Graff et al., 2021). Recently, there has been a market entry of large, non-agrifood IT or tech companies such as IBM or Microsoft (Durani, 2020; Hamann, 2020a). Market concentration is significant, suggesting positive returns to scale and first-mover advantages (Rotz et al., 2019).

On the demand side, actors are significantly less concentrated and organized. While some large agroholdings employ CTOs and operate own drone fleets, most farmers are not in a position to articulate demand in a decisive way. They only use technologies, which are easy to use and promise immediate payoffs (Gabriel & Gandorfer, 2020). Service providers and cooperatives might eventually emerge as crucial actors in-between, but need to build up the necessary capacities and develop new operational models (Ciruela-Lorenzo et al., 2020). In the future, downstream actors, such as food processors, retailers, CPG companies, certifiers and even consumers might become important actors, as the desire for traceability increases and new business models allow for a more direct engagement with primary producers (Durani, 2020).

Networks

Networks play a central role for the development of the innovation system (Bergek et al., 2008b). Formalized multistakeholder networks, that transcend traditional structures and involve relevant outside actors still need to develop. For policy developments in the EU, the Strategic Working Group on AKIS of the Standing Committee on Agricultural Research has emerged as a focal point (EU SCAR AKIS, 2019). In addition, the European Commission has assembled stakeholders ad hoc with regards to specific issues such as development of European Agricultural Data Space. Similar initiatives have been pursued at the member state level by public and private actors such as the German association of digital companies, BITKOM. The most advanced initiative on the international level seems to be the FAO Digital Council.

Farmer-based organizations (FBOs), which traditionally play a huge role in shaping agricultural policy, only represent a particular interest group in the innovation system. Notably, in the participation process for the European Agricultural Dataspace, just one contribution came from the FBO side (Copa Cogeca), next to several contributions from agtech companies and alliances (CEMA) or outside actors like the International Data Spaces Association. Still, FBOs might play a crucial role in the innovation system, as they represent the most important user group. Potentially, they could contribute to demand articulation and institutional development. A step in that direction can already be seen in the EU Code of Conduct for Agricultural Data Sharing (van der Burg et al., 2020). FBOs might also turn into proactive transmitters of knowledge, offering training and advice to their members.

Finally, a key role for connecting stakeholders accrues to research and advisory institutions, who often form the nexus of Agricultural Knowledge and Innovation Systems (AKIS) and consortia in funding schemes (Kernecker et al., 2021). However, they often do not fulfill that role effectively, as they themselves lack relevant knowledge and do not have the necessary links to data sciences and engineering (van Es & Woodard, 2017).

Institutions

Institutions in the TIS framework are defined in the sense of institutional economics, that is, the standards, laws, and cultural norms forming the "rules of the game" (North, 1992). In that regard, European agricultural and food regulation possesses a number of general characteristics, which affect the innovation system for digital technologies. Agricultural policy and regulation in particular has historically been "exceptional" with regards to competition, free movement or environmental law. Despite some tendencies to "normalize," this *agricultural exceptionalism* is still in many ways alive (Purnhagen, 2019). One key feature is the strong orientation of agricultural policies toward production and income. Sustainability has played an increasing but still relatively minor role, for example, through cross-compliance requirements, agri-environment-climate measures (AECMs) and statutory requirements like the nitrate directive. Similarly, digitalization (Garske et al., 2021) and innovation in general (Schebesta, 2021) have not been a particular focus of regulation, which rather emphasizes the precautionary principle and a bio-originalist approach. Food law has evolved on a somewhat different trajectory, being strongly centralized at the EU level and offering dense regulation especially on food safety and labelling (Purnhagen, 2019). The focus however lies on health, consumer protection and the common market rather than innovation or sustainability. Concrete linkages between agricultural and food law only exist in specific areas, notably the PDO/PGI system and organic agriculture.

Regarding relevant digital technologies, few specific regulations exist at all. Technologies are subject to general provisions, for example, on product safety (Härtel, 2019). Standard setting has mostly been industry-driven, with policy makers only starting to enter the picture (Kosior, 2019a). Digital innovation also only plays a limited role in agricultural administration. While the integrated administration and control system provides a digital basis for CAP subsidy management and some digital applications are used for control (e.g., satellite data for cross-compliance checks), administration in general is far from being "digitalized." Even for the most regulated products, like wine, where regulation requires seamless documentation from the vineyard to the shelve, integrated digital systems are only starting to be built.

This institutional situation can be seen as typical for emerging innovation systems, which are characterized by an incomplete "institutional alignment" (Bergek et al., 2008b). Achieving "institutional alignment" can be regarded as one of the key challenges for further development.

ANALYSIS OF FUNCTIONAL DYNAMICS

The following describes key potentials and challenges for each of the seven essential functions in the TIS framework and analyzes how they are addressed in the F2F strategy.

Knowledge development and diffusion

The first and foremost function of the TIS is the development and diffusion of knowledge. Knowledge encompasses different aspects, such as technical understanding, practical application or marketing. It can be developed and diffused in multiple ways (Bergek et al., 2008b). Digital technologies are characterized by particular learning curves and scale effects: For example, more ground data improves the performance of AI-based applications; technologies used for application (e.g., yield maps) also allow for knowledge creation through on-field trials; remote data processing allows for more efficient analysis (Asseng & Asche, 2019). Digital technologies also open new channels for knowledge diffusion, such as platforms for advisory services, e-commerce, and exchange of user experience. Knowledge development and diffusion thus has the potential to become a self-sustaining process.

Still, significant sociotechnical challenges exist: Bottlenecks already arise at the very first step: Compared to other sectors, remarkably little data is digitized (Durani, 2020). Reasons include missing infrastructure in rural areas, but also a lack of trust. Even where data is available, a lack of interoperability standards, driven by monopolistic behavior, is complicating its use by other actors (Kosior, 2019b; Rotz et al., 2019; Zeb et al., 2021). Technological complexity also poses unresolved challenges (Weltzien, 2016). While simple applications may already allow for efficiency gains, the great potential of data-driven agriculture lies in sophisticated models that integrate data on weather, soil, applications, yields, and so forth at high resolutions. Processing this "mega-big" data is technically and even physically difficult (Hamann, 2020a).

Data regulation could ideally pose a comparatively smaller problem, as it is generally supporting the free flow of nonpersonal data (Anzini, 2020). Still, key questions remain unsolved, especially how farmers can profit from sharing their data. The EU Code of Conduct for Agricultural Data Sharing, developed by different European Farmers' Organizations promotes the concept of *data sovereignty*. This approach however seems economically inefficient and will not change distributive results between farmers and agritech companies (Atik & Martens, 2021). It might therefore fail build trust (van der Burg et al., 2020). Besides data issues, significant challenges arise from a lack of digital literacy. Skill profiles in the agriculture and food industry are changing at a rapid pace (Hamann, 2020b). Advisory service providers themselves need to be trained (Kelly, 2020). Agricultural universities are often disconnected from research in data science (van Es & Woodard, 2017) just as vice-versa data scientists lack agronomic knowledge (Durani, 2020).

Knowledge development and diffusion in the F2F strategy

The F2F strategy clearly puts research, innovation, knowledge and skill development at the center of its efforts: Basically, the entire Chapter 3 "Enabling the transition" is devoted to these topics. The strategy foresees dedicated funding of 11 billion EUR under the Horizon programs as well as additional support for initiatives through the EIP-Agri and the Regional Development Fund. It provides for scaled up support to AKIS, notably through Member States' CAP funds, an update of the European Skills Agenda and advisory services for SME through the Enterprise Europe Network. It also foresees considerable physical and digital infrastructure development to overcome technical challenges. It promises full access to fast broadband internet in rural areas by 2025, investment in the Copernicus Earth Observation program, as well as instauration of a Farm Sustainability Data Network, and a common European Agriculture Data Space in line with the European data strategy.

The F2F strategy thus addresses some of the central challenges regarding knowledge development: It clearly recognizes the need to build up knowledge and skills on all levels and shows determination to provide the necessary financial and infrastructural resources. However, given the controversial discussion on data sovereignty (Klerkx et al., 2019), one might have desired more clarity on the values that govern the European agricultural data space. It could have made clear, that agricultural data is a public good and represents *environmental information*. It could have proposed to directly or indirectly incentivize data provision.

Guidance of search

A second key function of the TIS lies in its ability to guide actors to join the system and determine its direction. Essential factors in this respect are the visions, expectations, and beliefs regarding the system's growth potential, a clear articulation of demand from lead customers, technical bottlenecks, regulatory pressure, and general trends, such as demographics (Bergek et al., 2008a).

Belief in the growth potential of digital agriculture seems to be enormous with political actors and industrial leaders from inside and outside the agritech sector (Lajoie-O'Malley et al., 2020). Appraisal is more nuanced on the user side, especially from farmers (Weltzien, 2016). Adoption critically depends on a quick return on investment and easy applicability (Gabriel & Gandorfer, 2020; Shang et al., 2021). Especially for small farmers, adoption is often not economically viable. Regulatory pressure so far is limited: fertilization or pesticide limits and respective documentation duties may pose incentives to invest in technology, but only apply in certain areas. Demographic trends do not favor technology adoption: Farmers are getting older, while tech developers do not seem particularly drawn to agriculture (Rotz et al., 2019).

Guidance of search in the F2F strategy

The F2F strategy puts great emphasis on new value opportunities, notably carbon sequestration, the bio-based circular economy and renewable energy (Chapter 2.1). These may draw new actors to the innovation system. It also increases regulatory pressure, by providing various hard and soft targets and setting out a concrete regulatory agenda in Annex 1. However, in the view of the author, the Commission could have gone further in its regulatory ambition by taking inspiration from other industrial sectors: For example, it could have moved from a *Good Agricultural Practice* to a *Best Available Techniques* approach like in industrial emissions (Möckel, 2015), at least for large users and crucial technologies. It could have proposed measures that directly target agritech companies, such as the fleet reduction obligations (like in Regulation [EU] 2019/1242 for heavy-duty vehicles) or phaseout obligations for certain technologies. Finally, it could have directly addressed outside actors, notably tech companies, and provide specific incentives to join the agrifood innovation system.

Challenges also arise from the F2F strategy's strong focus on organic agriculture. While organic farming certainly has driven a lot of relevant technological innovations such as mechanical weeding, the organic framework is in several ways inimical to innovation (Purnhagen et al., 2021). It thus may even offer paradoxical incentives for farmers (see below).

Entrepreneurial experimentation

The third key function in the TIS framework relates to entrepreneurial experimentation to reduce uncertainty regarding technologies, applications and markets (Bergek et al., 2008b). Digital technologies in that regard profess some general properties in favor of experimentation: they can be used from everywhere, usually pose low entry costs, allow for new business models and offer new value categories (Satalkina & Steiner, 2020). With some caveats these features also apply to digital technologies in the agrifood sector: For example, digital applications allow for on-farm experiments and new ways of connecting practice and R&D (Asseng & Asche, 2019). They can also be integrated in sharing economy business models (Mittermayr, 2020).

Compared to other agrifood innovations, such as NPBTs, experimentation with digital technologies also faces few regulatory restrictions. Only general regulations apply, like product safety requirements or air traffic regulations for drones (Härtel, 2019; Kosior, 2019a).

Challenges for entrepreneurial experimentation arise mostly from the enormous sociotechnical complexity. Technology development requires a deep, integral understanding of issues such as agronomy, data science, and food chemistry (Durani, 2020). At the same time, entrepreneurs confront issues like digital literacy, trust, and financial constraints on the user side. For many applications, seasonality poses a considerable problem, as there are limited opportunities for trial and error. Typical strengths of digital innovations, such as early prototyping and "design with user" (Satalkina & Steiner, 2020) cannot be realized easily in this context. Very often, new products, business models and mindsets must be developed at the same time.

Entrepreneurial experimentation in the F2F strategy

The F2F strategy supports entrepreneurial experimentation primarily through dedicated funding schemes that extend to the private sector (especially the EIP-Agri). However, it fails to explicitly provide for new niches. First and second pillar CAP subsidies, including the new ecoschemes, certainly do not provide such niches or favor innovative approaches (see below). The European Agricultural Data Space creates new possibilities for independent developers. However, it is unclear, how far this potential can be leveraged, given the simultaneous discussion on data sovereignty. In general, the F2F strategy does not refer to regulatory tools for experimentation such as the Innovation Principle from the Commission's "Better regulation toolbox" (Schebesta, 2021), "innovation deals," or "regulatory sandboxes" (Henning et al., 2021).

Market formation

Market formation in the TIS framework is seen as a multistep process: First, nursing markets need to evolve to provide "learning spaces," followed by bridging markets and finally self-sustaining markets (Bergek et al., 2008b). Current surveys suggest that concrete markets for digital applications mostly exist for technologies that are easy to use and immediately pay off (Gabriel & Gandorfer, 2020). Investment costs and training needs pose significant obstacles, as financial and human capital constraints limit producers' room for maneuver. The market responds to these challenges, for example, through sharing economy models, or combinations of products and advisory services or financial guarantees. However, none of these business models solves the central challenge of financially valorizing the sustainability benefits of digital technologies. As long as these benefits are not compensated, neither technology providers nor users have an incentive to develop and use sustainable technologies. As with other eco-innovations, market formation thus critically depends on regulation (Cecere et al., 2014).

Market formation in the F2F strategy

The F2F strategy clearly seems determined to open new ways of financially valorizing sustainability, especially carbon sequestration and the bioeconomy. It even promises a regulatory framework for carbon sequestration (Chapter 2.1). However, the F2F strategy does not foresee a fundamental reform of the CAP subsidy mechanisms and—indeed—no such reform is implemented in the CAP 2023–2027. The new CAP does include some new "sustainable" elements, such as the full conditionality of direct payments, enhanced GAEC and SMR standards, the new "ecoschemes" in the first pillar and larger envelope for AECMs in the second pillar. A satellite-based area-monitoring system is meant to ensure full compliance (NIVA, 2021). However, neither conditional direct payments, nor ecoschemes nor AECMs provide markets for innovation. They reward established procedures with cost-based subsidies and offer no perspective to get rich by pioneering new technologies. Even if predefined precision farming applications are subsidized through second pillar funds, this central challenge remains unaddressed: Farmers cannot earn more by producing more sustainably. This leaves them at the same time too rich and too poor to try new ways. In fact, ecoschemes and AECMs might even drive farmers into investing less in innovation.

To initiate self-sustaining technological change, true price signals must exist (Acemoglu et al., 2012). Pesticide taxation (Berendse, 2017; Böcker & Finger, 2016) or cap-and-trade schemes (Henning et al., 2021) for example would not only be a more efficient option to reduce pesticide use but also offer incentives for innovation. Organic farming could—in theory—deliver price signals, as it is rewarded by a significant premium on the market (and in future maybe even subject to tax incentives, cf. Chapter 2.4 of the F2F strategy). However, the existing organic regulation cannot really be considered as an evidence-based sustainability standard.

In the energy transformation, policy resolved the issue of market formation through guaranteed feed-in tariffs. Of course, this model cannot simply be transposed to the food sector, which is producing many different products instead of just one. However, there are certainly ways to valorize intermediate outputs or the provision of agricultural data, or introduce more competitive elements, especially for large farms.

The lack of clear profit opportunities also poses the risk that the F2F strategy's proposition of achieving sustainability through innovation will not be shared or even resisted by farmers' unions. So far, farmers have often perceived environmental standards as a cut to their margins, not a chance to earn money. This perspective will not change if ecoschemes and the new "conditionality" put additional pressure on them without offering opportunities to earn more money.

Legitimation

Legitimation of new technologies in the eyes of all stakeholders probably represents the most essential function for an innovation system in its formative phase besides knowledge development (Bergek et al., 2008c). It is a key condition for institutional alignment and usually requires the formation of new advocacy coalitions to overcome locked in belief systems and "group think."

As described above, digital technologies face few legitimation problems with consumers and policymakers (Pfeiffer et al., 2021). The urban populace embraces their environmental benefits and increased transparency. Digital farming even blends well with organic regulation, which often stifles innovation due to its bio-originalist approach (Schebesta, 2021).

Resistance mainly comes from potential users, namely, farmers. This resistance not only relates to a lack of exposure or digital literacy. It is based on a concrete distrust of technology providers and a fear of the profound structural implications of digitalization (Rotz et al., 2019). Social sciences have recently started to analyze the changes digitalization brings to farmer identity, skills, and work (Klerkx et al., 2019): Farmers move from being self-reliant, "hands-on" food producers to data-driven managers of complex ecosystems. Gender stereotypes are changing. In the long-run, digitalization may even lead to "Farming without Farmers" (Asseng & Asche, 2019), both in a technological and in a sociological sense. Consequently, support for policy initiatives from key lobby groups like farmers' unions is not unequivocal: While some technology-oriented associations (like German DLG) recognize the potential to change the image of agriculture and even formulate new visions of a "future farmer," other interest groups try to block political reforms seen as suffocating agriculture.

Legitimation in the F2F strategy

At first sight, the F2F strategy strengthens the legitimation of digital technologies by acknowledging their sustainability benefits and proposing various support measures (see above). However, it does not address the legitimacy concerns of farmers and remains silent on the structural and social implications of the sustainability transformation. In the very first sentence, the F2F strategy promises to "leave no one behind." Later, it vaguely commits to "improving the incomes of primary producers" (p. 4). Apart from that, social or structural issues are not mentioned at all.

From an innovation system's perspective, the Commission should have addressed the structural and social implications of the F2F strategy more openly. Sustainability transitions research shows, that the failure to address losers often leads to increased political resistance from advocacy groups (Köhler et al., 2019). It is typically the less innovative firms that lobby for protection (Bombardini et al., 2021). How exactly farm structures will be affected by digitalization is in fact an open question (Klerkx et al., 2019). Digital technologies do offer potentials for small scale production (Asseng & Asche, 2019). The Commission could propose policies to use those potentials, for example, strengthening cooperatives' digital capacities. It could implement policy instruments inspired by behavioral economics, such as nudging and debiasing, to overcome locked in beliefs. It might even formulate a positive vision of future farms that could be mainstreamed throughout legislation. While such a vision would certainly meet resistance, it could allow for a reconfiguration of discourse and the formation of new advocacy coalitions. The strategy's credo "Leave no one behind" suggests a transformation without losers. This is impossible, given the enormous challenges that need to be overcome. It is also contrary to innovation, characterized as a process of constant "creative destruction" (Schumpeter, 1912).

Resource mobilization

The sixth function in the TIS framework relates to the innovation system's capacity to mobilize financial resources. Investment climate has generally been favorable to innovations in recent years, with low interest rates and a broad array of investors searching for new value opportunities. Postpandemic development, of course, is not foreseeable. Despite the broad availability of finance, investments usually pose a significant concern for farms, as margins in agriculture are low. Public investment support therefore plays a large role.

Resource mobilization in the F2F strategy

The F2F strategy promises to mobilize significant public (Horizon and EIP-AGRI) and private funds (through budget guarantees from the Invest EU Fund) for innovative agriculture. It also refers to new general rules on sustainable finance (EU taxonomy). Overall, this seems to be a remarkable improvement to the current situation. The biggest challenge regarding resource mobilization has already been described under "market formation": As long as there are no clear profit opportunities for sustainable technologies, the potential to leverage external finance for transforming the agrifood sector remains limited. As an immediate step the definition of Best Available Techniques (see above) might help to mobilize resources for the introduction of new technologies, given the growing interest in ESG standards in the financial sector.

Development of positive externalities

The final function in the TIS framework consists in the development of positive externalities. In order to positively affect the TIS, positive externalities must not be mere side-effects of using the technology (e.g., GHG reduction), but concrete benefits to other sectors, such as knowledge spillovers, shared intermediary goods or a common talent pool (Bergek et al., 2008b). For digital technologies in agriculture, positive externalities seem most likely to develop with neighboring innovation systems such as the bioeconomy and renewable energy. For issues like weather data, externalities might also concern other sectors like transport. Traceability fostered through digital technologies might allow for new value opportunities in retail. Significant externalities might also concern the digitization of administration: Because of stringent food safety requirements (where the F2F approach is already a reality) and detailed CAP demands, the administration of the agrifood sector is already quite data-heavy. The proposed area-monitoring system will add another dimension to this. Finding ways to creatively use this data for the good of the sector, for example, through AI or "regtech" (i.e., automated compliance), could set examples for many other policy areas. Finally, positive externalities of digital agriculture may concern rural development in general. Digital infrastructures, a more sustainable image of agriculture and some of the social changes described above (e.g., changing gender stereotypes, less manual work) could contribute to making rural life more attractive, changing current urbanization patterns and resolving demographic challenges.

Positive externalities in the F2F strategy

The F2F strategy clearly establishes the relation between sustainable agriculture, the circular bio-based economy and renewable energy. It also devotes a lot of attention to linkages in the food chain, which could improve value creation in retail (possibly benefiting farmers). However, the F2F strategy misses the chance to relate to major recent policy initiatives in the digital sphere (most of which were equally prioritized by the German Council presidency 2020) and establish more links with the European regional development policies.

DISCUSSION

As described above, innovation systems in their formative phase critically depend on achieving "institutional alignment." This alignment is not a centralized "top–down" process and requires actions from all actors. Still, there seem to be at least three ways in which a high-level policy document like the F2F strategy can help to align institutions for the benefit of the innovation system: First, it can provide clarity and stability with regard to political objectives and establish policy coherence. Second, it can strengthen concrete policies to support innovation. Third, it can remove structural barriers to innovation and resolve institutional lock-ins. While the F2F strategy performs rather well on the first two aspects, it seems to fall short on the last one.

Clear, stable, and coherent agenda for sustainability and digital transformation

As described above, neither sustainability nor (digital) innovation have traditionally played a large role in European agricultural and food policy. In this regard, the F2F strategy sends an important signal from the highest policy level. It provides a clear commitment to sustainable innovation and takes a holistic view of food system. Sustainability transformations need long-term stability (König et al., 2018), and the F2F strategy, with its concrete targets and commitment until 2030, provides just that. This seems true, even though the concept of food sustainability remains somewhat elusive, and not all targets are very clear (Schebesta & Candel, 2020). It can at least be hoped that clarity will be provided by the concrete policy measures foreseen in Annex 1, notably the "legislative framework for sustainable food systems."

The F2F strategy can also be lauded as a major step toward policy coherence. It establishes an unprecedented level of alignment, not only between agricultural and food policy, but also with research and environmental policy. The new mechanism for adopting CAP national strategic plans might also help to bring greater coherence to member state implementation.

The F2F strategy's clarity and coherence can positively affect the innovation system, even though it might have provided more incentives for outside actors to join and might have established more links with the digital and regional development policies of the EU.

Innovation, knowledge, and skill development as central values

The F2F strategy puts innovation, knowledge and skill development right in the center of its efforts to transform the agrifood system. Essentially the entire Chapter 3 "Enabling the

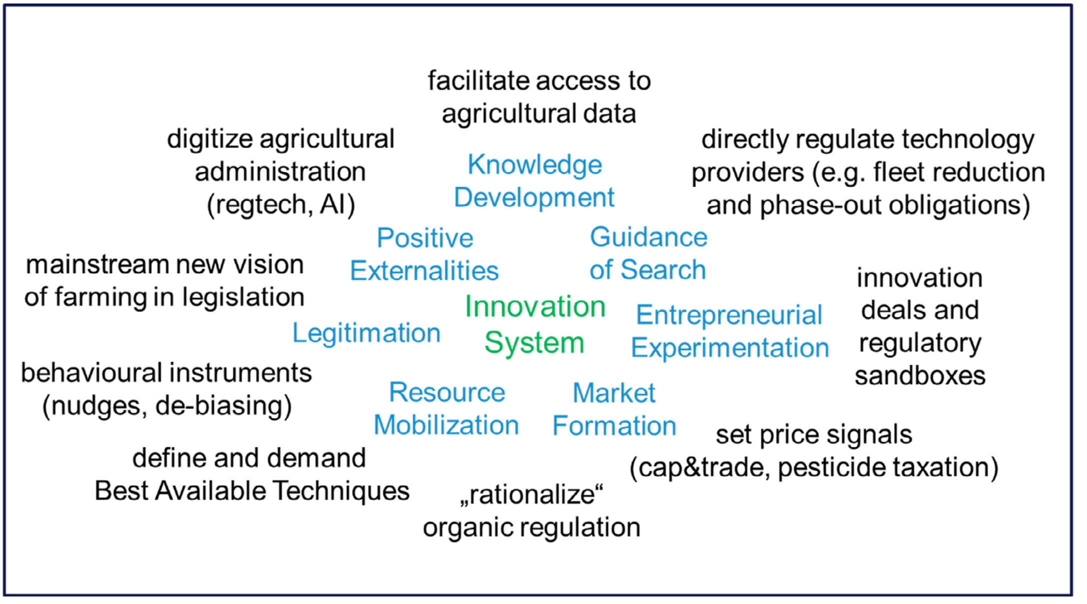

FIGURE 2 Regulatory tools to support digital innovation in the agrifood sector. *Source*: Own illustration [Color figure can be viewed at wileyonlinelibrary.com]

transition" is devoted to these aspects. The F2F strategy also recognizes the central role of the digital transformation. Central elements of the F2F strategy include mainstreaming precision farming and the use of artificial intelligence as well as establishing relevant infrastructures, both physical (broadband) and digital (Agricultural Data Space). The strategy's ambition is mirrored by the new CAPs cross cutting objective of modernization, knowledge sharing and innovation, and digitalization, including the strengthening of AKIS in all member states.

The positive effects for innovation development might be even stronger, if the use of digital infrastructures and data provision were incentivized directly or if available regulatory tools to allow for entrepreneurial experimentation were created.

Remove structural barriers to innovation and resolve institutional lock-ins

Despite the significant reorientation in values, the F2F strategy does not propose a radically different structure of the CAP. It remains silent on structural implications and proposes a transformation, which "leaves no one behind." From an innovation system perspective this approach lends itself to two major criticisms: On the one hand, the F2F stratey fails to create the market conditions for innovation to thrive. It neither allows for getting rich by pioneering sustainable technologies, nor creates the risk of failure for those who do not adapt. In the existing CAP system, no price signals exist, that allow for a self-sustaining technological change. Some of the subsidies might even disincentivize innovation. On the other hand, the F2F strategy fails to create legitimacy of digital technologies with the main user group, farmers. While remaining silent on social issues might have made the strategy more acceptable in the short run, it creates long-run problems, as it does not address losers or allow for new advocacy coalitions to form.

The strong focus of the F2F strategy on organic farming is at least ambivalent in both regards. If the regulatory framework for organic was reformed in a way, that it actually comprises the most sustainable, rather than traditional practices, it could be a powerful vector for enhancing environmental sustainability. In its current form, it risks misdirecting resources and causing leakage of environmental problems to other regions of the world (Henning et al., 2021).

CONCLUSION

The article has assessed the F2F strategy from the perspective of innovation systems. It has shown that the F2F strategy provides a clear, coherent and stable framework for a sustainability transformation of the agrifood sector that clearly supports innovation. It can thus be seen as a paradigm-shifting "mission" statement for the innovation system, addressing central demands of recent sustainable innovation systems research (Hekkert et al., 2020; Urmetzer & Pyka, 2019). It has also described shortcomings of the strategy, notably in creating favorable market conditions for innovation and building legitimacy with farmers, as the most important users. Figure 2 summarizes regulatory tools, that could address some key weaknesses and that could be implemented without contradicting the F2F objectives. It is the major strength of the F2F strategy that it promotes clear priorities and values creating an environment where institutional lock-ins (also regarding issues like biotechnology) can be resolved "peacefully" in the future.

REFERENCES

Acemoglu, Daron, Philippe Aghion, Leonardo Bursztyn, and David Hemous. 2012. "The Environment and Directed Technical Change." *American Economic Review* 102(1): 131–66.

Adegbeye M.J., Ravi Kanth Reddy P., Obaisi A.I., Elghandour M.M.M.Y., Oyebamiji K.J., Salem A.Z.M., Morakinyo-Fasipe O.T., Cipriano-Salazar M., Camacho-Díaz L.M. 2020. Sustainable agriculture options for production, greenhouse gasses and pollution alleviation, and nutrient recycling in emerging and transitional nations - An overview. *Journal of Cleaner Production* 242: 118319. https://doi.org/10.1016/j.jclepro.2019.118319

Aghion Philippe, Howitt Peter. 1992. A Model of Growth Through Creative Destruction. *Econometrica* 60(2): 323. https://doi.org/10.2307/2951599

Akcigit, Ufuk, and John van Reenen. 2021. "The Economics of Creative Destruction." In *A Festschrift Symposium in Honor of Philippe Aghion and Peter Howitt*.

Anzini, Martina. 2020. "Promoting Data Sharing in the EU: A Regulatory and Antitrust Perspective." In *XXXIV EURAGRI Conference*.

Asseng, Senthold, and Frank Asche. 2019. "Future Farms without Farmers." *Science Robotics* 4(27): eaaw1875.

Atik, Can, and Bertin Martens. 2021. "Governing Agricultural Data and Competition in Data-Driven Agricultural Services: A Farmer's Perspective." JIPITEC 12 (2021): 370–96

Barreiro-Hurle, Jesus, Mariia Bogonos, Mihaly Himics, Jordon Hristov, Ignacio Pérez-Domiguez, Amar Sahoo, Guna Salputra, Franz Weiss, Edoardo Baldoni, and Christian Elleby. 2021. "Modelling Environmental and Climate Ambition in the Agricultural Sector with the CAPRI Model." JRC Technical Report.

Basso Bruno and Antle John. 2020. Digital agriculture to design sustainable agricultural systems. *Nature Sustainability* 3(4): 254–6. https://doi.org/10.1038/s41893-020-0510-0

Beckman, Jayson, Maros Ivanic, Jeremy Jelliffe, Felix Baquedano, and Sara Scott. 2020. "Economic and Food Security Impacts of Agricultural Input Reduction under the European Union Green Deal's Farm to Fork and Biodiversity Strategies." U.S. Department of Agriculture, Economic Research Service. https://ageconsearch.umn.edu/record/307277

Berendse, Frank. 2017. "Add a Tax to the EU Agricultural Policy." *Nature* 543(7645): 315.

Bergek, Anna, Marko P. Hekkert, and Staffan Jacobsson. 2008a. *Functions in Innovation Systems: A Framework for Analysing Energy System Dynamics and Identifying Goals for System Building Activities by Entrepreneurs and Policy Makers*. Cheltenham, UK: Edward Elgar.

Bergek, Anna, Marko Hekkert, Staffan Jacobsson, Jochen Markard, Björn Sandén, and Bernhard Truffer. 2015. "Technological Innovation Systems in Contexts: Conceptualizing Contextual Structures and Interaction Dynamics." *Environmental Innovation and Societal Transitions* 16: 51–64.

Bergek, Anna, Staffan Jacobsson, Bo Carlsson, Sven Lindmark, and Annika Rickne. 2008b. "Analyzing the Functional Dynamics of Technological Innovation Systems: A Scheme of Analysis." *Research Policy* 37(3): 407–29.

Bergek, Anna, Staffan Jacobsson, and Björn A. Sandén. 2008c. "'Legitimation' and 'Development of Positive Externalities': Two Key Processes in the Formation Phase of Technological Innovation Systems." *Technology Analysis and Strategic Management* 20(5): 575–92.

Bigliardi, Barbara, Eleonora Bottani, and Giorgia Casella. 2020. "Enabling Technologies, Application Areas and Impact of Industry 4.0: A Bibliographic Analysis." *Procedia Manufacturing* 42: 322–6.

Böcker, Thomas, and Robert Finger. 2016. "European Pesticide Tax Schemes in Comparison: An Analysis of Experiences and Developments." *Sustainability* 8(4): 378.

Bombardini Matilde, Cutinelli Rendina Olimpia and Trebbi Francesco. Lobbying Behind the Frontier. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3901577

Cecere Grazia, Corrocher Nicoletta, Gossart Cédric, and Ozman Muge. 2014. Lock-in and path dependence: an evolutionary approach to eco-innovations. *Journal of Evolutionary Economics* 24(5): 1037–65. https://doi.org/10.1007/s00191-014-0381-5

Ciruela-Lorenzo, Antonio M., Ana R. Del-Aguila-Obra, Antonio Padilla-Meléndez, and Juan J. Plaza-Angulo. 2020. "Digitalization of Agri-Cooperatives in the Smart Agriculture Context. Proposal of a Digital Diagnosis Tool." *Sustainability* 12(4): 1325.

Dolfsma Wilfred and Leydesdorff Loet. 2009. Lock-in and break-out from technological trajectories: Modeling and policy implications. *Technological Forecasting and Social Change* 76(7): 932–41. https://doi.org/10.1016/j.techfore.2009.02.004

Durani, Vineet. 2020. "Stakeholder Statement by the Director of Agri-Food Industry, Azure Global, Microsoft Corporation at the High-Level Dialogue on the Establishment of the International Platform for Digital Food and Agriculture."

Eastwood C., Klerkx L., Ayre M., and Dela Rue B. 2019. Managing Socio-Ethical Challenges in the Development of Smart Farming: From a Fragmented to a Comprehensive Approach for Responsible Research and Innovation. *Journal of Agricultural and Environmental Ethics* 32(5-6): 741–68. https://doi.org/10.1007/s10806-017-9704-5

Eastwood C., Klerkx L., and Nettle R. 2017. Dynamics and distribution of public and private research and extension roles for technological innovation and diffusion: Case studies of the implementation and adaptation of precision farming technologies. *Journal of Rural Studies* 49: 1–12. https://doi.org/10.1016/j.jrurstud.2016.11.008

Ehlers, Melf-Hinrich, Robert Huber, and Robert Finger. 2021. "Agricultural Policy in the Era of Digitalisation." *Food Policy* 100: 102019.

El Bilali Hamid and Allahyari Mohammad Sadegh. 2018. Transition towards sustainability in agriculture and food systems: Role of information and communication technologies. *Information Processing in Agriculture* 5(4): 456–64. https://doi.org/10.1016/j.inpa.2018.06.006

EU SCAR AKIS. 2019. "Preparing for Future AKIS in Europe." *4th Report of the Strategic Working Group on Agricultural Knowledge and Innovation Systems (AKIS).*

Gabriel, Andreas, and P D Markus Gandorfer. 2020. "Landwirte-Befragung 2020 Digitale Landwirtschaft Bayern."

Garske, Beatrice, Antonia Bau, and Felix Ekardt. 2021. "Digitalization and AI in European Agriculture: A Strategy for Achieving Climate and Biodiversity Targets?" *Sustainability* 13: 4652.

Graff, Gregory D., Felipe de Figueiredo Silva, and David Zilberman. 2021. "Venture Capital and the Transformation of Private R&D for Agriculture." In *Economics of Research and Innovation in Agriculture*, edited by Petra Moser, 213–52. Chicago, IL: University of Chicago Press.

Greenacre, Philip, Robert Gross, and Jamie Speirs. 2012. *Innovation Theory: A Review of the Literature*. London, UK: Imperial College Centre for Energy Policy and Technology (ICEPT).

Hamann, Hendrik. 2020a. “Stakeholder Statement by the Chief Scientist for Geoinformatics and AI Applications, International Business Machines (IBM) at the High-Level Dialogue on the Establishment of the International Platform for Digital Food and Agriculture.”

Hamann, Karen. 2020b. “Down-Stream Sectors: Digitalisation and Automation in the Food Industry - Implications for Skills and Science.” In *XXXIV EURAGRI Conference*.

Härtel Ines. 2019. Agrar-Digitalrecht für eine nachhaltige Landwirtschaft 4.0. *Natur und Recht* 41(9): 577–86. https://doi.org/10.1007/s10357-019-3571-y

Hekkert Marko P., Janssen Matthijs J., Wesseling Joeri H., and Negro Simona O. 2020. Mission-oriented innovation systems. *Environmental Innovation and Societal Transitions* 34: 76–9. https://doi.org/10.1016/j.eist.2019.11.011

Henning, Christian, Peter Witzke, Lea Panknin & Michael Grunenberg 2021. “Ökonomische Und Ökologische Auswirkungen Des Green Deals in Der Agrarwirtschaft.”

Kelly, Tom. 2020. “The Digitalisation of Agriculture – Challenges for Advisory Services.” In *XXXIV EURAGRI Conference*.

Maria Kernecker, Maria Busse, and Andrea Knierim. 2021. Exploring actors, their constellations, and roles in digital agricultural innovations. *Agricultural Systems* 186: 102952. https://doi.org/10.1016/j.agsy.2020.102952

Klerkx Laurens, Jakku Emma, and Labarthe Pierre. 2019. A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. *NJAS - Wageningen Journal of Life Sciences* 90-91: 100315. https://doi.org/10.1016/j.njas.2019.100315

Klerkx, Laurens, and David Rose. 2020. “Dealing with the Game-Changing Technologies of Agriculture 4.0: How Do we Manage Diversity and Responsibility in Food System Transition Pathways?” *Global Food Security* 24: 100347.

Köhler, Jonathan, Frank W. Geels, Florian Kern, Jochen Markard, Elsie Onsongo, Anna Wieczorek, Floortje Alkemade, et al., eds. 2019. “An Agenda for Sustainability Transitions Research: State of the Art and Future Directions.” *Environmental Innovation and Societal Transitions* 31: 1–32.

König Bettina, Janker Judith, Reinhardt Tilman, Villarroel Morris, and Junge Ranka. 2018. Analysis of aquaponics as an emerging technological innovation system. *Journal of Cleaner Production* 180: 232-43. https://doi.org/10.1016/j.jclepro.2018.01.037

Kosior, Katarzyna 2019a. “From Analogue to Digital Agriculture. Policy and Regulatory Framework for Agricultural Data Governance in the EU.”

Kosior Katarzyna. 2019. Towards a New Data Economy for EU Agriculture. *Studia Europejskie -Studies in European Affairs* 23(4): 91–107. https://doi.org/10.33067/se.4.2019.6

Lajoie-O'Malley Alana, Bronson Kelly, van der Burg Simone, and Klerkx Laurens. 2020. The future(s) of digital agriculture and sustainable food systems: An analysis of high-level policy documents. *Ecosystem Services* 45: 101183. https://doi.org/10.1016/j.ecoser.2020.101183

Lal Rattan, Smith Pete, Jungkunst Hermann F., Mitsch William J., Lehmann Johannes, Nair P.K. Ramachandran, McBratney Alex B., de Moraes Sá João Carlos, Schneider Julia, Zinn Yuri L., Skorupa Alba L.A., Zhang Hai-Lin, Minasny Budiman, Srinivasrao Cherukumalli, and Ravindranath Nijavalli H. 2018. The carbon sequestration potential of terrestrial ecosystems. *Journal of Soil and Water Conservation* 73(6): 145A-52A. https://doi.org/10.2489/jswc.73.6.145a

Lindner, Ralf, Stephanie Daimer, Bernd Beckert, Nils Heyen, Jonathan Koehler, Benjamin Teufel, Philine Warnke & Sven Wydra 2016. “Addressing Directionality: Orientation Failure and the Systems of Innovation Heuristic. Towards Reflexive Governance. No. 52.” Fraunhofer ISI Discussion Papers - Innovation Systems and Policy Analysis.

Malerba Franco, and McKelvey Maureen. 2020. Knowledge-intensive innovative entrepreneurship integrating Schumpeter, evolutionary economics, and innovation systems. *Small Business Economics* 54(2): 503–22. https://doi.org/10.1007/s11187-018-0060-2

Markard, Jochen. 2020. “The Life Cycle of Technological Innovation Systems.” *Technological Forecasting and Social Change* 153: 119407.

Mittermayr, Claudia. 2020. “Which Are the New Business Models?” In *XXXIV EURAGRI Conference*.

Möckel Stefan. 2015. ‘Best available techniques’ as a mandatory basic standard for more sustainable agricultural land use in Europe?. *Land Use Policy* 47: 342–51. https://doi.org/10.1016/j.landusepol.2015.04.021

Nevzorova, Tatiana, and Emrah Karakaya. 2020. “Explaining the Drivers of Technological Innovation Systems: The Case of Biogas Technologies in Mature Markets.” *Journal of Cleaner Production* 259: 120819.

Nilsson, Magnus & Clarissa Sia-Ljungström 2013. "The Role of Innovation Intermediaries in Innovation Systems."

NIVA. 2021. "Operationalising Agro-Climatic and Agro-Environmental Indicators for Future CAP." NIVA Policy Brief No. 2.

Noleppa, Steffen & Matti Cartsburg 2021. "The Socio-Economic and Environmental Values of Plant Breeding in the EU and Selected EU Member States." HFFA Research Paper.

North, Douglass. 1992. "Institutions, Ideology, and Economic Performance." *Cato Journal* 11(3): 477–96.

Pfeiffer Johanna, Gabriel Andreas, and Gandorfer Markus. 2021. Understanding the public attitudinal acceptance of digital farming technologies: a nationwide survey in Germany. *Agriculture and Human Values* 38 (1): 107–28. https://doi.org/10.1007/s10460-020-10145-2

Purnhagen, Kai Purnhagen, Kai Peter, The End of Agricultural Exceptionalism in EU Free Movement Law and Competition Law after Lisbon? (May 20, 2019). Wageningen Working Papers of Law and Governance 3/2019, Available at SSRN: https://ssrn.com/abstract=3391134

Purnhagen Kai P., Clemens Stephan, Eriksson Dennis, Fresco Louise O., Tosun Jale, Qaim Matin, Visser Richard G.F., Weber Andreas P.M., Wesseler Justus H.H., and Zilberman David. 2021. Europe's Farm to Fork Strategy and Its Commitment to Biotechnology and Organic Farming: Conflicting or Complementary Goals?. *Trends in Plant Science* 26(6): 600–6. https://doi.org/10.1016/j.tplants.2021.03.012

Purnhagen Kai, and Wesseler Justus. 2021. EU Regulation of New Plant Breeding Technologies and Their Possible Economic Implications for the EU and Beyond. *Applied Economic Perspectives and Policy* 43(4): 1621–37. https://doi.org/10.1002/aepp.13084

Pyka, Andreas, Kristina Bogner, and Sophie Urmetzer. 2019. "Productivity Slowdown, Exhausted Opportunities and the Power of Human Ingenuity—Schumpeter Meets Georgescu-Roegen." *Journal of Open Innovation: Technology, Market, and Complexity* 5(3): 39.

Qaim Matin. 2020. Role of New Plant Breeding Technologies for Food Security and Sustainable Agricultural Development. *Applied Economic Perspectives and Policy* 42(2): 129–50. https://doi.org/10.1002/aepp.13044

Rose, David C., and Jason Chilvers. 2018. "Agriculture 4.0: Broadening Responsible Innovation in an Era of Smart Farming." *Frontiers in Sustainable Food Systems* 2: 87.

Rotz Sarah, Duncan Emily, Small Matthew, Botschner Janos, Dara Rozita, Mosby Ian, Reed Mark, and Fraser Evan D.G. 2019. The Politics of Digital Agricultural Technologies: A Preliminary Review. *Sociologia Ruralis* 59(2): 203–29. https://doi.org/10.1111/soru.12233

Satalkina, Liliya, and Gerald Steiner. 2020. "Digital Entrepreneurship and its Role in Innovation Systems: A Systematic Literature Review as a Basis for Future Research Avenues for Sustainable Transitions." *Sustainability* 12(7): 2764.

Schebesta, Hanna. 2021. "Designing Policies to Unlock Agri-Technologies Potential." ELO 2021 Innovation Conference.

Schebesta Hanna, and Candel Jeroen J. L. 2020. Game-changing potential of the EU's Farm to Fork Strategy. *Nature Food* 1(10): 586–588. https://doi.org/10.1038/s43016-020-00166-9

Schumpeter, Joseph. 1912. *Theorie Der Wirtschaftlichen Entwicklung*. Leipzig: Duncker & Humblot.

Shamshiri, Redmond, Cornelia Weltzien, Ibrahim Hameed, Ian Yule, Tony Grift, Siva Balasundram, Lenka Pitonakova, Desa Ahmad, and Girish Chowdhary. 2018. "Research and Development in Agricultural Robotics: A Perspective of Digital Farming." *International Journal of Agricultural and Biological Engineering* 11(4): 1–11. https://doi.org/10.25165/j.ijabe.20181104.4278

Shang, Linmei, Thomas Heckelei, Maria K. Gerullis, Jan Börner, and Sebastian Rasch. 2021. "Adoption and Diffusion of Digital Farming Technologies - Integrating Farm-Level Evidence and System Interaction." *Agricultural Systems* 190: 103074.

Sharma Rohit, Kamble Sachin S., Gunasekaran Angappa, Kumar Vikas, and Kumar Anil. 2020. A systematic literature review on machine learning applications for sustainable agriculture supply chain performance. *Computers & Operations Research* 119: 104926. https://doi.org/10.1016/j.cor.2020.104926

Sozer, Nesli. 2020. "Digitalisation Shaping the Consumer Landscape." In *XXXIV EURAGRI Conference*.

Urmetzer, Sophie, and Andreas Pyka. 2019. "Innovation Systems for Sustainability." In *Decent Work and Economic Growth. Encyclopedia of the UN Sustainable Development Goals*, edited by Walter Leal Filho, Anabela M. Azul, Luciana Brandli, Amanda L. Salvia, and Tony Wall. Cham: Springer.

van der Burg Simone, Wiseman Leanne, and Krkeljas Jovana. 2021. Trust in farm data sharing: reflections on the EU code of conduct for agricultural data sharing. *Ethics and Information Technology* 23(3): 185–98. https://doi.org/10.1007/s10676-020-09543-1

van Es, Harold, and Joshua Woodard. 2017. "Innovation in Agriculture and Food Systems in the Digital age." In *The Global Innovation Index 2017: Innovation Feeding the World*, edited by Soumitra Dutta, Bruno Lanvin, and Sacha Wunsch-Vincent, 97–104. Geneva, Switzerland: World Intellectual Property Organization.

Weltzien, Cornelia. 2016. "Digital Agriculture – Or why Agriculture 4.0 Still Offers Only Modest Returns." *Landtechnik* 71: 66–8.

Zeb Akhtar, Soininen Juha-Pekka, and Sozer Nesli. 2021. Data harmonisation as a key to enable digitalisation of the food sector: A review. *Food and Bioproducts Processing* 127: 360–70. https://doi.org/10.1016/j.fbp.2021.02.005

How to cite this article: Reinhardt, Tilman. 2022. "The farm to fork strategy and the digital transformation of the agrifood sector—An assessment from the perspective of innovation systems." *Applied Economic Perspectives and Policy* 1–20. https://doi.org/10.1002/aepp.13246