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Agricultural startups' visions of a sustainable agri-food future: a comparative case study in rural and urban Germany

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Abstract
Current agriculture and food systems are major drivers of global environmental change and are linked to numerous ethical concerns. Against this backdrop, agri-startups are perceived as promising catalysts for new and more sustainable agri-food systems. However, their potential to actually contribute to sustainability transformations has been understudied. The aim of this study is to narrow this gap by analyzing German agri-startups' visions and how these co-produce prevailing or novel sociotechnical imaginaries in agriculture. We conduct an in-depth qualitative comparative case study of agri-startups (n=16) in both a rural–agrarian and an urban (nonagricultural) setting in Germany. We identify four visions with varying scales and scopes of envisioned change, with different conceptualizations of sustainable agri-food transformation: (1) *Reconfiguration of Sociomaterial Structures*, (2) *Partial Redesign*, (3) *Optimization of Value Chains*, and (4) *Incremental Improvement*. Our findings highlight the relevance of the sociospatial context of agri-startups and innovation processes in co-producing agri-food futures. While urban startups tend to envision more holistic changes, rural agri-startups rather envision applied and pragmatic changes. We critically discuss the differences among these visions and their limited ability to transform existing agri-food systems. Finally, we highlight that agri-startups largely perpetuate existing imaginaries and that the disruptive character that is often attributed to (agri-) startups needs critical scrutiny.

Keywords Sociotechnical visions · Agricultural startups · Sustainability transition · Transformation · Agricultural innovation

Introduction

Agriculture is the world's single largest driver of global environmental change (Rockström et al. 2017). Current agricultural and food systems strongly contribute to climate change (Lenka et al. 2015), biodiversity loss (Dudley and Alexander 2017), nutrient cycle disruption (Schipanski and Bennett 2012), and other types of ecological degradation. Additionally, numerous ethical concerns and social implications are associated with agriculture, particularly regarding a lack of animal welfare (Grethe 2017) and labor conditions (van Rijn et al. 2020). Moreover, although there are arguments that enough food is produced in principle (Weis 2007), the issues of the global distribution of food and the consequent issues of accessibility and affordability remain, entailing a lack of food justice and sovereignty that does not occur only in the Global South (Clendenning et al. 2016).

Agricultural startups (agri-startups[1]), among other actors, promise to contribute to solving these multifaceted agricultural issues through self-declared innovative products and services (Fairbairn et al. 2022). Across sectors, startups are

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[1] We deliberately use the term "agri-startups" because it is more inclusive than the term "agtechs," by encompassing also startups whose innovations are not primarily technologically driven (see Table 1 for details on agri-startups' innovations).

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Table 1 Comparison between the two selected case study regions, lower Saxony (rural area) and Berlin (urban area)

Parameter	Lower Saxony	Berlin
Total area (Statistisches Bundesamt 2022)	47.709 km^2	891 km^2
Population density (Statistisches Bundesamt 2022)	168 inhabitants per km^2	4.127 inhabitants per km^2
Percentage of overall startup foundations in Germany 2022 (Kollmann et al. 2022)	7.5%	19.1%
Percentage of agricultural startup foundations between 2009 and 2017 (Huchtemann and Theuvsen 2018)	9%	24%
Number of farms	33.900 (in 2022, BMEL 2022)	47 (in 2020, Amt für Statistik Berlin-Brandenburg 2020)
Arable land	2.584.000 ha (in 2022, BMEL 2022)	1.864 ha (in 2020, Amt für Statistik Berlin-Brandenburg 2020)

defined as nascent ventures with a repeatable and scalable business model based on innovative products or services (Blank and Dorf 2012). Most recently, the agri-food sector has put forth a rising number of startups (Burwood-Taylor et al. 2023). Schirmer et al. (2021) explain this recent growth through the increasing importance of digitalization and new digital technologies, such as the Internet of Things (IoT), the growing amount of available data, and advances in data science and automation combined with artificial intelligence (AI) and robotics. However, there are also agri-startups whose innovations have a less technical but more systemic or social character, focusing on social value creation, e.g., through the creation of jobs for young people or by providing education about nutrition and agriculture (Zanzi et al. 2021). All these startups are accompanied by many promises and expectations. These range from mere economic interests in profitability to a mission orientation, including environmental or social goals and sustainable agri-food futures (Schaltegger and Wagner 2011; Horne and Fichter 2022). Often, startups mobilize a combination of economic interests, moral values, and technological progress to attract investments (Hogarth 2017; Fairbairn et al. 2022).

However, how these promises materialize and how agri-startups can contribute to a sustainability-oriented transformation in agriculture are contested among scholars. Technology-oriented agri-startups often promise to contribute to greater social good, improving food production in the name of sustainability, safety, or efficiency (Fairbairn et al. 2022). These startups rhetorically position themselves in front of possible investors as a "profitable investment opportunity as well as a moral obligation, allowing food production to cope with neo-Malthusian and environmental threats" (Sippel and Dolinga 2023, p. 475). Agri-startups are also discussed as actors introducing innovations that may challenge existing sociotechnical regimes and incumbent actors, possibly leading to shifts in the configuration of power relations and discursive hegemony (Wolfert et al. 2017; Steup et al. 2019; Klauser and Pauschinger 2021). However, scholars highlight the risk that agri-startups, whose innovations especially aim at an increasing degree of digitalization, may lead to 'digital solutionism' and thus to a mismatch of problems and solutions (Guthman and Butler 2023). This could fuel unintended side effects and perpetuate or even exacerbate existing agricultural sustainability-related problems (Heimstädt 2023a; Zscheischler et al. 2022).

We consider start-ups and their innovations as 'co-produced' (Jasanoff 2004) through particular social, political and economic orders while at the same time reproducing these. Consequently, societal and political beliefs that startup entrepreneurship is elementary for achieving socio-economic development and meeting the grand challenges of the 21st century (Weiss et al. 2023) and a recent surge in financial investments in agri-startups[2] shape their development. Mostly, agri-startups also align well with the tech-optimism of the broader society that shapes the agri-food sector in terms of novel robots, drones and other equipment applicable in the field (Sippel and Dolinga 2023) and have been argued to be able to solve socio-environmental problems (e.g., Friedrich et al. 2022a). However, the idea of co-production (Jasanoff 2004) reminds us that startups—particularly their expectations and visions—also transport and create social, economic, and political orders (Chilvers and Longhurst 2015). In this paper, we intend to contribute to the understanding of this 'co-production', in particular how startups' sociotechnical visions relate to existing or trickle into new broader sociotechnical imaginaries (Jasanoff and Kim, 2015; Jasanoff et al. 2007). In the latter case, we also relate to the co-production of so-called 'vanguard visions' that can be understood as future visions that are not yet widely shared among and accepted by larger publics but that aspire to bring transformative change through innovations and challenge established sociotechnical imaginaries (see Hilgartner 2015)[3]. This is of relevance since Polzin (2024)

[2] Global investments in agri-startups in 2019: $7.0 bn; 2020: $9.7 bn; 2021: $15.9 bn, 2022: $15.2 bn (Burwood-Taylor et al. 2023).

[3] Hilgartner (2015, p. 3 et seq.): "By a 'sociotechnical vanguard' I mean to designate relatively small collectives that formulate and act intentionally to realize particular sociotechnical visions of the future that have yet to be accepted by wider collectives, such as the nation.

describes how German agriculture is characterized by a sociotechnical imaginary linked to the idea of Germany as an industrialized country ('Industrieland'), which is focused on productivity and co-produced through historical, robust political, scientific, and economic formations that build a so-called 'iron triangle'. This imaginary stands in contrast to a sustainability-oriented transformation and the 'agriculture turnaround' ('Agrarwende'), a vanguard vision that calls for more fundamental change (ibid.). Consequently, the question emerges whether startups and their sociotechnical visions can challenge this institutionalized imaginary and contribute to sustainability-oriented transformation in agriculture, as well as how they link to (other) vanguard visions such as the German 'Agrarwende'.

In light of these considerations, this study aims to contribute to an in-depth understanding of agricultural startups in Germany. Based on an analysis of the normative orientations, epistemic origins, and material commitments of the sociotechnical visions of these startups, we discuss how and whether their future visions can be considered vanguard visions that have the ability to (re)shape consolidated imaginaries. This, we argue, allows for indicative insights into an understanding of whether and how these startups contribute to sustainability-oriented transformation in German agriculture. By comparing startups originating from two contrasting regions in Germany (see Section *Research design*), we want to gain insights into the variety of startups and understand how these are entangled with and fueled by place-specific aspects, such as regional identities, expectations, and desires (e.g., Feola et al. 2023), as well as how they co-produce particular spatial orders (Chateau et al. 2021). We ask the following research questions.

- What visions are formed in and enacted through agricultural startups in Germany, and how do they relate to broader sociotechnical imaginaries?
- How do these visions differ according to place, and what sociospatial reconfigurations do they produce?

We answer these questions through a comparative case study of agri-startups in two contrasting German regions, namely, Berlin (an urban region far from agriculture) and the Oldenburger Münsterland and Osnabrück region in Lower Saxony (a rural and agri-intensive region). Our results respond to wider debates on the role, contribution, and limits of agri-startups in agri-food sustainability transformations.

Conceptualizing the co-production of future visions and sociospatial contexts

Sociotechnological developments, such as those occurring as part of agri-startups, are the product of actors' own inventions while being socially embedded and consequently shaped by collectively held (and institutionalized) sociotechnical imaginaries (e.g., Smith 2015; Baur and Iles 2023). These developments are not neutral, yet create and transport normative convictions about what ought to be (Jasanoff et al. 2007; Jasanoff and Kim 2009). Identifying these visions that are intertwined with the material developments provides insights into the normative frameworks and social orders the actors are shaped by and (re)produce. These aspects can reveal actors' potential contributions to sustainability-oriented transformations, particularly the ways and models in which change is envisioned and enacted (Herren et al. 2020). In this paper, we understand agri-startups as agents of potentially novel and 'vanguard visions' (Hilgartner 2015). These visions, manifested in the discursive promises and material commitments of startups, can trickle into collectively held imaginaries and thus have a significant influence on broader sociotechnical developments (Middelveld and Macnaghten 2021).

As locations where future visions are developed and enacted, agri-startups become sites of co-production where "making identities, making institutions, making discourses and making representations" (Jasanoff 2004: 6) occur. Jasanoff (2004) argues that the idiom of 'co-production' describes how knowledge and technology are produced through social orders. Yet, this loops back, and knowledge and technology bring forward particular social orders. Co-production consequently stresses the "constant intertwining of the cognitive, material, social, and normative" (ibid., p. 6) and highlights the importance of not only ideas and values but also concrete physical objects or spaces, equally fueling the semiotic dimension and forming the social. In this reading, the 'social' and 'technological' are inextricably interwoven and constantly produced together, forming sociomaterial arrangements. From this perspective, co-production also offers a way to understand the power relations at work in technoscientific formations. Vanguard visions follow this line of thought. Focused on envisioning and shaping future technological and societal development, vanguard visions constitute the forefront of technological and scientific innovation. They have the potential to challenge existing paradigms and contribute to sociotechnical transformations (Hilgartner 2015; Beck et al. 2021; Middelveld and Macnaghten 2021). Standing in contrast to

These vanguards and their individual leaders typically assume a visionary role, performing the identity of one who possesses superior knowledge of emerging technologies and aspires to realize their more desirable potentials. Put otherwise, these vanguards actively position themselves as members of an avant-garde, riding and also driving a wave of change but competing with one another at the same time."

more established sociotechnical imaginaries or prevailing visions of the future, though, can make them either short-lived or rapidly evolving, with the respective interactions with the prevailing imaginaries being highly dependent on specific contexts (Polzin 2024).

We argue that (vanguard) visions are also shaped by and embedded in sociospatial constellations, such as place-specific identities and local problems, historically grown regional economies and innovation systems, including their specific actors' networks, while producing particular spatial orders (Granovetter 1985; Chateau et al. 2021; Feola et al. 2023; Friedrich and Hendriks 2024). As an example, such sociospatial and natural constellations produce the place-specific shape of agriculture, which is dependent on local/regional socioecological and socioeconomic aspects, such as the soil, climate and biodiversity in proximity to markets and infrastructure. In Germany, this, for example, has led to strong clusters of livestock farming around Oldenburger Münsterland, whereas other regions remain dedicated primarily to arable farming due to nutrient-rich soils (Windhorst 2016; Bichler and Häring 2003). Following Feola et al. (2023), places and the intertwined identities of different actors can co-produce different spatial–material visions (also for the same physical space) that express different spatial framings, highlighting how place-based identities fuel the emergence of future visions. Consequently, visions and imaginaries are never 'spatially neutral' but are underpinned by a particular vision of sociospatial orders and relations, encompassing particular forms of space, scale[4] and place (Chateau et al. 2021). Since ontologies can differ across places, for sociotechnical visions, this implies that "*where* they are materializing has shaped ideas of *what* they are and might achieve" (Sexton 2020, p. 464). For example, research has shown that local, place-specific identities, socioeconomic legacies, and political cultures can form unique regional innovation cultures that underpin the normative orientation of innovations, i.e., the sort of innovations are deemed desirable and permissible, how they need to be framed to gain legitimacy, and how they fit into existing regulatory frameworks. This results in innovations acquiring a unique and place-specific 'cultural fingerprint', as Pfotenhauer et al. (2023) argue.

In our study, we consider these theoretical elaborations relevant for exploring startups' sociotechnical visions. While we do not include all of them in our empirical analysis, we use these considerations, particularly the idiom of co-production, in the discussion of our research. For the analysis of our empirical material, we employ the framework of Longhurst and Chilvers (2019) and combine it with place- and space-related aspects. Longhurst and Chilvers (2019) suggest analyzing not yet widely shared visions through a four-dimensional framework of meanings, knowings, doings, and organizings. Like Hilgartner (2015) and by referring to Jasanoff (2004), Longhurst and Chilvers (2019) follow the idea of co-production in their framework and argue that these four aspects are co-produced together among sociomaterial collectives. According to Chilvers and Longhurst (2015), *meanings* reflect the normative framings of issues and imaginaries for sociomaterial arrangements; *knowings* comprise the cognition and knowledge that shape and are produced through sociomaterial arrangements; *doings* represent the material commitments produced by sociomaterial arrangements; and *organizings* relate to the social and governing organizational structures reflected in the way sociomaterial arrangements are configured (Chilvers and Longhurst 2015, p. 30). These dimensions represent common sites of co-production (cf. Jasanoff 2004). As an example, meanings relate to the making of identities and discourses, while organizings reflects the making of institutions. Consequently, we adopt the four categories of the framework of Chilvers and Longhurst (2015) to study the agri-food visions of startup founders. Because of the above-described relevance of place, scale, and space in both agriculture and innovation processes, we add a fifth cross-cutting dimension, 'geography' (see Fig. 1), to account for how visions are influenced based on place-specific aspects, while simultaneously bringing forward particular agrarian sociospatial orders (see also Chateau et al. 2021; Feola et al.

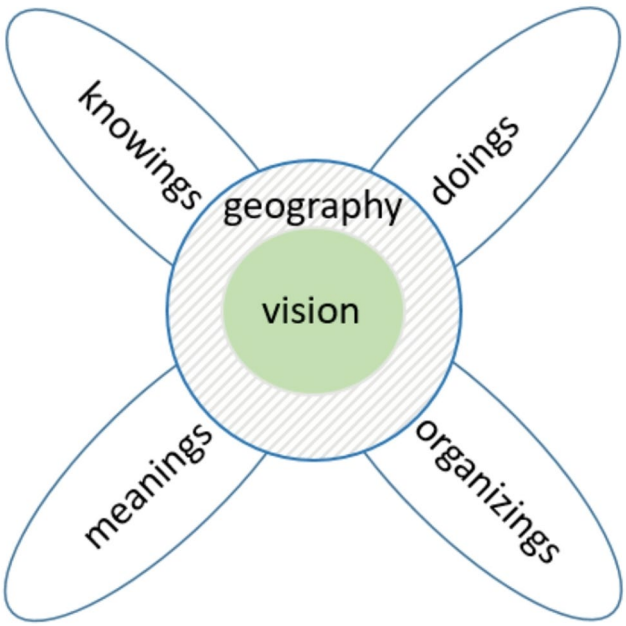

Fig. 1 Co-production of visions (after Longhurst and Chilvers 2019), geography as cross-cutting dimension

[4] We consider scale as a level, meaning a specific point where phenomena can be observed and analyzed within a broader framework (Sayre 2005), such as a field, a value chain, or a societal subsystem.

2023; Friedrich and Hendriks 2024; Späth and Rohracher 2010). Figure 1 represents these five dimensions.

Methods and research design

We apply a qualitative comparative and type-building case study approach to examine the visions of agri-startups in two contrasting German regions. Our study builds upon semi-structured interviews with 16 agri-startup founders and a deductive-inductive approach to data analysis.

Research design

To examine the sociotechnical visions of agri-startups, we chose a qualitative and 'diverse' case study approach (Seawright and Gerring 2008) for two contrasting regions in Germany (a rural, agri-intensive region vs. an urban region). In Germany, half of the land is used for farming, and German agriculture is characterized by a great variety of farming methods ranging from intensive to extensive ecological approaches in both livestock and crop farming (BMEL 2020). Moreover, Germany is home to some of the most impactful international (and global) players in the agri-food sector, including Bayer, BASF, Fendt, and Claas. Thus, agribusiness has become the second most profitable industry within the manufacturing sector, surpassed only by the automotive industry (Janze et al. 2022). Examining the visions of agri-startups against the backdrop of Germany's heterogeneous agricultural landscape and the economic importance of its agri-food sector offers important insights for both the German context and beyond. Therefore, we utilize a case study design that comprises two contrasting ('diverse', cf. Seawright and Gerring 2008) case study regions (Berlin and Lower Saxony) to understand the socio-spatial differences in shaping the pursued visions. The first site is the 'vibrant startup metropolis' of Berlin, which has the second highest rate of startup foundations across all sectors (Kollmann et al. 2022) and the highest rate in the agri-food sector (Huchtemann and Theuvsen 2018). The second site encompasses the rural regions of Oldenburger Münsterland (OML) and Osnabrück in Lower Saxony[5], which are located in northwestern Germany. These regions have the greatest amount of arable land in Germany (BMEL 2022), with OML having one of the highest densities of intensive livestock farming in Germany and being one of the most intensive agricultural landscapes in Germany (Niedersächsisches Ministerium für Ernährung, Landwirtschaft und Verbraucherschutz 2022). In the past, these regions produced some impactful sociotechnical innovations that led to currently common farming methods, so the region has been labeled the 'Silicon Valley' (Windhorst 2016) of modern agriculture[6]. Given the requirements for future agriculture, the region is expected to live up to this reputation (Windhorst 2016). Table 2 illustrates the differences between the two case study sites using selected outline data.

Data collection

According to Blank and Dorf (2012), startups are characterized as temporary organizations constituted to search for a repeatable and scalable business model, which sets them apart from regular companies. Thus, general self-employment and small business activities are different from entrepreneurship. The latter is strongly influenced by the Schumpeterian concept of creating new economic activities and organizations, with the primary goal of introducing development, renewal, or even transformation to society and the economy. This differentiates startups from non-innovative self-employment (Stam 2008). Therefore, we selected young companies that are less than ten years old and have a self-declared innovative business model that is new to the market. We focused on the upstream segment of agricultural value chains[7], including all steps before final consumers are involved, since these steps are directly linked to agricultural production, unlike innovations in the downstream part, such as online delivery services, which have no immediate impact on how agricultural goods are produced. To identify relevant startups for our study, we conducted online research on the platforms Crunchbase, Berlin-Startups.net, start-green.net, and Seedhouse. We also used snowball sampling through LinkedIn and during the agricultural exhibition 'Internationale Grüne Woche' in Berlin. Based on these data, we created a list of potential startups, 20 located in Berlin and 9 located in Lower Saxony, from which we randomly selected interview partners. Between January and March 2023, we conducted a total of 16 expert (semistructured) interviews (Menz 2002) with agri-startup founders. Eight of these startups were based in Lower Saxony, and the other eight were based in Berlin. The interviews were structured along the following topics: (a) the background of the founder and the startup; (b) the problem perception and solution approach of the startup; (c) the challenges in the agri-food system beyond the scope of

[5] For better readability, we will use the state name Lower Saxony to represent the two regions of Oldenburger Münsterland and Osnabrück in the following text.

[6] E.g., the company "Grimme" located in OML argues that its innovations have been decisive for the automation of potato harvesting (see https://group.grimme.com/en/history, last checked in January 2024).

[7] Following Sturgeon (2001), we define value chains as a sequence of productive, meaning value-added, activities that lead to a certain end use.

Table 2 Key data of the interviewed startups based on self-reported information on the online business platform linkedin (as of November 2023) as well as detailed description of their innovation

Startup	Innovation	Founding year	Number of employees	Location
IP1	Part-time vegetable gardening	2020	11–50	Berlin
IP7	Digital platform for commodity trading	2019	11–50	Berlin
IP8	Environmental footprint-compensation scheme for businesses through the enactment of nature-positive agricultural measures	2021	2–10	Berlin
IP9	Plant-based eggs	2021	11–50	Berlin
IP12	Paludiculture business concept	2021	2–10	Berlin
IP13	Automatic picture analysis and consultation by AI	2015	201–500	Berlin
IP14	Vegetable gardening as a leisure activity	2020	2–10	Berlin
IP15	Plant-based fish	2020	11–50	Berlin
IP2	Automatic picture analysis, consultation by AI and enactment by a robot	2022	2–10	Lower Saxony
IP3	CO_2 compensation scheme for businesses and individuals through humus building	2021	2–10	Lower Saxony
IP4	Seed testing	2021	2–10	Lower Saxony
IP5	Essential oils for barns	2020	2–10	Lower Saxony
IP6	AI-based pig monitoring	2020	2–10	Lower Saxony
IP10	Nature-based seed treatment	2016	11–50	Lower Saxony
IP11	AI-based poultry and pig monitoring	2020	11–50	Lower Saxony
IP16	Sensor-based irrigation system	2021	2–10	Lower Saxony

the startup's innovation; (d) possible futures for the agri-food system; and (e) the startup's role within a sustainable transformation of the agri-food system. We conducted the interviews both online and in person in both German and English and then translated the German quotes. The interviews lasted between 27 and 98 min, were recorded with the interviewees' informed consent, and were fully transcribed for analysis. The following table provides an overview of the selected startups.

Data analysis

Considering the aim of this study, we used a type-building qualitative text analysis (Kuckartz 2014) to uncover common ground and differences in the sociospatial production of visions among agri-startups. A type-building qualitative text analysis is characterized by cases (interviews) that are combined into types (visions) on the basis of similarities in selected features (provided by the theoretical framework). A type is characterized by a distinct combination of features. Elements of the same type should be as similar as possible, whereas the different types should be as dissimilar and heterogeneous as possible. The totality of all identified types forms the typology. We followed the five steps of a type-building qualitative text analysis as explained by Kuckartz (2014): (1) determining the attribute space, i.e., defining attributes that are relevant for the striven type building; (2) grouping individual cases and building typologies, which are compared and contrasted to determine which one is best suited to the data; (3) describing the constructed types and typology in greater detail; (4) assigning cases to the created types; and (5) presenting both individual types and the typology according to their characteristics, as well as analyzing the relationships between the types and the secondary variables.

We used MAXQDA software to process the data. In the first step, we used deductive coding on the basis of the a priori theoretical categories depicted in our theoretical framework, namely, *meanings*, *knowings*, *doings*, and *organizings* (Chilvers and Longhurst 2015). In the second step, we used open coding to identify additional inductive (sub) categories directly from the material, e.g., reflecting certain values such as awareness, recognition, or efficiency. We exported the coded elements into a code summary table and summarized the contents of the inductively coded elements per case and deductive category. In the final step, we developed types of visions by (1) determining our attribute space by using the four dimensions of sociotechnical visions described in our theoretical framework and (2) grouping the cases according to similarities in the deductive categories. For example, cases whose meanings include awareness and knowledge contrast with cases whose meanings reflect a belief in market-based solutions. We continued by (3) describing the identified types in greater detail regarding their characteristics within the four dimensions, (4) assigning further cases with similar characteristics to the respective types, and (5) presenting and analyzing the different types according to our research questions. In an iterative process of going back and forth, the first author of this paper coded the material and discussed the coding scheme with the remaining two authors in recurring meetings to ensure intercoder reliability. Table 3 in the appendix displays our deductive and inductive categories for type building.

Table 3 Overview of the categories used for coding and type-building. The top row shows the deductive categories, with the respective inductive categories in the columns below. Each inductive category includes an anchor example

Meanings	Knowings	Doings	Organizings
Awareness & Knowledge "We want to make people conscious of the massive production of eggs and all the consequences that this brings." (IP9)	**Personal Relation to Agriculture** "I grew up in the district of Cloppenburg on a farm. We have 10000 laying hens, […] plus 19 hectares of arable land, a few meadows, and a bit of forest—A classic smallholding in that sense. […] I quickly immersed myself in farming, and I worked a lot at home [on the farm]." (IP5)	**Social Learning** "We do quite a lot with schools. […] That's super important because there is a total distance between young people and agriculture. I don't want to say that everyone has to become a farmer. But food is simply an important part of our lives. And everyone needs some kind of relationship with it in order to be able to deal with it in a healthy way." (IP1)	**Microfarms &Urban Farming** "So, it is also meant to activate the street base. And this is where our idea also meets the current trend that we hope will grow which is clearing up the streets from car parking. […] The idea is also to integrate in some of these spaces other functions that are new amenities for the residents." (IP14)
Connecting Consumers and Agriculture "We believe that strengthening the relationship with agriculture can change a number of our problems in the agricultural landscape." (IP1)	**Biology** "I studied biology and also specialized in ecology and botany." (IP4)	**Environment and Animal Protection** "What we produce here is 100% peat-free humus. […] If you apply it to a field, it is immediately processed again. That allows the farmer to build up humus. At the same time, he can make more nutrients available to the plant. And that is actually the idea behind it. […] You create more ecology. You create more biodiversity." (IP3)	**Classical Farming** "We simply have to ensure that we still have animal husbandry here in Germany, that we ensure food security, also through our own production and not just through imports. Certainly with more modern standards." (IP11)
Believe in Technical Solutions "We are trying to set up lots of pairs of eyes in stables, which then automatically analyze the whole thing so that they can give a notification: There's a complication. […] that's the vision—to become a better pair of eyes than the farmers because they can't be there all the time." (IP6)	**Professional Agriculture or Horticulture** "And the idea came about because we ourselves are farmers. […] We both did a bachelor's degree in agriculture, then a master's degree, also in agriculture, but two master's degrees each. He has a master's in climate science, I have a master's in management." (IP8)	**Climate Neutrality/Nature Positivity** "It's about helping companies to organize their value chain in a nature-positive way, not only in terms of CO_2 neutrality or positivity but also in other dimensions, such as biodiversity, water cycles, and so on." (IP8)	**Peatland Farming & Agro-Forestry** "We will need something like paludiculture in the future in order to have these value-added cycles. Because what we're heading towards right now, like a coal phase-out, is the abandonment of regions. Because in the future, farmers will find their fields wet or will no longer be able to cultivate them." (IP12)
Market-based Solution "In an ideal system, politics would not have to intervene so much. To achieve this, I believe it is extremely important to assess the real environmental and social costs of what we are doing. Because that is what gives us the right basis for making decisions in order to shape the system." (IP10)	**Food Sector** "I specialized in the food industry relatively quickly during my studies. During my studies, I worked at the Centre for Sustainable Corporate Management. This is a scientific institute that mainly specializes in companies in the food industry." (IP1)	**Ecologic or Regenerative Agriculture** "With our technology, we want to support people who are interested in biointensive cultivation and regenerative agriculture." (IP2)	**(Intensive) Regenerative Agriculture** "We now also know that we can specifically promote the soil biome. In other words, improving the soil. We can then support a more vital plant, which ideally can even produce higher yields. That is the basic idea. And our overarching goal is actually to be a part of the transformation of agriculture." (IP10)
New Consumption Behavior "Our aim is to make seaweed suitable for everyday use and to turn it into a commodity in the food industry and to develop this raw material for the food industry." (IP15)	**Economics and/or Engineering** "After studying industrial engineering, I did my doctorate on the subject of networks, particularly in the field of innovation management, at the Entrepreneurship Chair." (IP7)	**Economy other** "And what we are also trying to do is to make it so easy to use by means of smartphones that even simple trainees can use the complex technology. So, in a way, we are trying to tackle the shortage of skilled labor a little." (IP16)	**Regionality** "Food should be used locally again. Because we do have the opportunity to grow apples here too. Or to grow other fruits and vegetables locally again. And not just from farms with 5,000 hectares. That's not the solution." (IP3)

Table 3 (continued)

Meanings	Knowings	Doings	Organizings
Time and/or Process Efficiency "We are making a direct contribution to making decisions more data-driven and at the same time reducing costs in the production process by eliminating a large amount of overhead through technological processing." (IP7)	**Consulting** "I spent the last four and a half years working as a management consultant at [blinded company name] Consulting, where I developed many business models, developed strategies and did organizational development." (IP12)		**Smallholder Farming** "So this idea that more space equals more efficiency or more production output is not necessarily always the case. Instead, it is also possible to think small and detailed and generate a high output." (IP10)
			Digitalization & Automation "Ultimately, this describes the process of the robot doing everything independently. It loads independently, manages the data independently, plans the mission, and drives fully autonomously over the beds. That is the autonomous operating concept for our robot." (IP2)

Results

Through our comparative and type-building case study, we identified four visions documented in the narratives of 16 agri-startup founders in Germany (for an overview, see Table 4). The identified visions are distinguished and characterized by idiosyncratic identities and problematizations, grounded in their respective sociospatial embedment, and materialize in both rather new and already established sociotechnical entanglements, each putting forward individual sociospatial orders, with particular forms of space, scale, and place. In the following, we first present Vision 1, which is rooted in an urban setting and entangles consumers and agriculture through a reconfiguration of sociospatial orders that tends to blur the classic characteristics of urban places as food-consuming and rural places as food-producing. Then, Visions 2 and 4, both originating in and deeply intertwined with rural–agrarian identities and places, with the objective of preserving traditional agrarian sociospatial orders in Germany. These two visions differ in the scale of their materializations, with Vision 2 materializing in 'regenerative' farming methods that require a comprehensive reorganization of the sociomaterial interplay of farmers, natural resources, and farming methods. Vision 4, in turn, employs incremental improvements of single production steps, offering easy-to-adapt artifacts that merely alter given sociomaterial configurations. Vision 3, whose extensive technology optimism seemingly exists detached from a certain sociospatial embedment, as it originates both in rural–agrarian and urban places, without being intertwined with either identity. Its focus lies in efficiency gains through entanglements of agrarian spaces and cutting-edge technology. Sociomaterial matters evoked by these, possibly affecting rural–agrarian places and identities, are barely considered. Finally, the differing foci of these vanguard visions on different aspects of agri-food systems, i.e., different scales and spaces of intervention, reinforce the notion that they can act in a complementary manner rather than in opposition to each other. In the following, we describe each vision following the developed coding tree (see Table 4).

Vision 1: Reconfiguration of sociomaterial structures

Vision 1 *Reconfiguration of Sociomaterial Structures* reflects the urban sociospatial embedment and identity of its innovation actors, i.e., being closer to consumers than to traditional farmers. Consumers constitute the vision's focal point, as they are to be made aware of the environmental, social, and ethical downsides of agri-food systems to introduce change to the latter. New value chains based on new farming models or plant-based products should enable consumers to adapt more sustainable consumption patterns, which in turn improves the environmental, social, and ethical conditions in agri-food systems. To make this more sustainable consumption possible, the vision's innovations target several sections of the respective value chains[8] at once, to be reconfigured through doings that differ in the type of employed technology in direct comparison with each other.

The vision's ***meanings*** are coined by a perceived alienation between modern, primarily urban societies and agriculture, as well as a lack of social awareness of grievances in the agri-food sector. Vision 1 misses a connection between citizens and food that transcends the purchase and consumption of food but includes an awareness of agricultural, environmental and health issues. This vision

[8] This means that each startup in which Vision 1 is co-produced addresses several parts of the respective value chain, i.e., preproduction, production, and processing, in contrast to addressing a single aspect within a specific production method.

Table 4 Overview of the identified visions co-produced in agri-startups and through their innovations, as well as their origin, enriched with IPs' quotes

Vision / Feature	Reconfiguration of Socio-material Structures	Partial Redesign	Optimization of Values Chains	Incremental Improvement
Doings	New value chains based on new farming models or plant-based products	Regenerative farming methods; remuneration of nature positive measures	AI supporting human decision-making in the field	(Technical) improvement of existing processes
Quotes	*IP 12: "There's a lack of business models. So, when we talk to farmers, they say, I'd love to do something else, but I need a business model. I need functioning value chains. I just need someone to take my biomass. If I rewet everything now and have the biomass, then it just lies around and nobody takes it off my hands. And that's where we go in advance in order to open up new economic perspectives. To reconcile climate protection with agriculture. And that's only possible with wet peatland farming."*	*IP 8: "It's about helping companies to organize their value chain in a nature-positive way. That means not only in terms of CO_2neutrality or positivity, but also in terms of other dimensions such as biodiversity, water cycles and so on. We analyze their current environmental footprint and then propose measures on how to achieve this through in-setting*, i.e., *with farmers or foresters, depending on the sector, through certain measures. These are agricultural and environmental measures, such as flower strips, agroforestry, hedges and so on, to ensure that it is demonstrably environmentally positive or enhancing and leads to an increase in biodiversity. And then, we monitor and certify this afterward for the companies that have paid for it."*	*IP 13: "We make the image recognition software for other companies […] so we get the images from their farmers. By analysing the metadata from these images, we understand which crops are being grown, at what time are they being grown, and what are the most common problems that farmers have. So we can say that for every single village, they have the following problems and then give recommendations in our app."*	*IP 16: "What we do is: we use our mini-computer to upgrade these old systems to modern systems. The result is that you can simply control these systems from home using a smartphone. And what we also offer is a sensor control system, where you simply put sensors in the ground next to the plants and the irrigation is then completely self-sufficient."*
Knowings	Economics, resource management, politics, architecture, communication studies Only partial connections to agriculture	Economics focusing on sustainability Founders come from an agricultural/ horticultural background	STEM[1] subjects Minor personal or professional connection to agriculture	Agricultural studies, economics and STEM Founders come from an agricultural background or have other personal connections to agriculture
Quotes	*IP 15: "My co-founder studied resource management and environmental protection, and I studied social and business communication. We both came across the topic of regenerative agriculture or the regenerative food industry in general in different ways over the course of time."*	*IP 3: "I'm a horticulturalist by training. I studied this and business. […] My grandparents were already horticulturists here and grew food, potatoes and vegetables, and flower bulbs. And they mixed our own substrates here, with peat even back then. So, we're all practitioners. I'm a practitioner too. And we all come from the world of practical experience."*	*IP 2: "I'm an industrial engineer by training and always focused on aerospace engineering. […] I'm actually more interested in the technical side."*	*IP 6: "I grew up on a farm myself, with conventional pig husbandry, in Osnabrück and that's where the original connection [to the startup idea] came from."*
Organizings	Regionality, less cultivated areas due to less livestock farming, more different kinds of farming systems in parallel *Scale*: societal subsystem	Regenerative, more diverse agriculture, more small-holder farming *Scale*: value chain	Sustainable cultivation of existing structures through data-based techniques and less human decision making; no monocultures, more crop rotation *Scale*: (upstream) value chain	Existing structures become more cost and time efficient; less human workforce needed *Scale*: agricultural process/production steps

Table 4 (continued)

Feature \ Vision	Reconfiguration of Socio-material Structures	Partial Redesign	Optimization of Values Chains	Incremental Improvement
Quotes	*IP 1: "I would like to have value chains that can be traced and experienced and that works particularly well with regionality."*	*IP 8: "We should think more in terms of circular economy and not just somehow passing the inputs from Bayer to Agravis by putting the fields in-between. I do believe that more value creation should go back into the hands of the original producers and that it can happen if the right incentives are put in place."*	*IP 2: "Agriculture needs to diversify, and that's just not the case at the moment. We want to address this broader positioning with our technology in order to support this, […] and try to work a bit more ecologically efficient."*	*IP 5: "As farmers, we always insist that it's called agricultural economy. Then, we also have to be entrepreneurs. Then, we also have to do business. No company has a business model that will be valid for another 20 years. In other words, the questions we have to ask ourselves are: how do we actually manage to cope with changing product life cycles? How do we manage to digitalize our companies?"*
Meanings	Missing connection between consumers and agriculture; societal component is part of new value chains; awareness and connections are to be built	Conventional farming methods are harmful to the environment; subsidies are misleading; market-based solutions shall reward farmers´ nature positive performance	Sustainable agriculture though data-based technology; AI enables reduction of agrochemicals; intensive agriculture can be sustainable	Technology fulfills demands for modern agriculture, i.e., improves animal welfare and quicker breeding of resilient crops
Quotes	*IP 14: "I think the potential is huge in schools if we manage to partner with schools and put our units there. The kids can have the experience of growing their own food and tasting it. I think that the impact of it in ten years it's huge. What they learn and the taste they develop, it will affect how much vegetables and fruit they would consume later in life. […] So, if you have access to education and change habits or create people's tastes, this is huge This would have great potential."*	*IP 10: "Conventional agriculture would be in a pretty bad position if you put a monetary value on it all. At the moment, we're taking the piss out of ourselves by simply not calculating the costs that are actually incurred. It's the same with artificial fertiliser production. The oil industry doesn't take all that into account either, otherwise Shell et cetera would make billions in losses if you calculated the social and environmental costs. It's a very big double standard. […] If the food trade were to implement this consistently, if the industry were to implement this consistently, if the farmer were to receive support for specific measures and see the real costs, which would have to be assessed, then I would have a realistic picture of where agriculture needs to develop. And we are constantly distorting that. I see that as very, very critical."*	*IP 13: "I believe that only digital solutions have the ability to create this kind of impact. In 2022, 5 million farmers used [startup name]. Even if you just assume that we only really helped 20% of them, which is a very low number, then we would have helped a million farmers with a digital solution that hardly costs anything. No NGO in the world can do that—educate a million people. No government can do that. Only digital solutions work."*	*IP 7: "I believe that there are an incredible number of technological achievements and fantastic production processes, especially in food production. However, as I said, many business processes are still far behind what is standard in other sectors today. And closing this gap […] is a huge efficiency gain for every single participant in the market. It saves costs and time."*
Innovations	Novel Farming System; Innovative Foods	Agribusiness Marketplaces; Agri-Biotechnology	Farm Management Software, Sensing & IoT	Agri-Biotechnology; Farm Management Software, Sensing & IoT; Agribusiness Marketplaces; Farm Robotics & Equipment
Spatial origin	urban	urban and rural	urban and rural	mainly rural

[1] STEM is an umbrella term covering the disciplines of science, technology, engineering, and mathematics.

deliberately encompasses nature conservation and animal welfare, which are to be improved through innovations that build consciousness among consumers and relations with the agri-food sector, as emphasized by IP9:

"We do not base ourselves really on just being vegan and addressing vegan and vegetarian people. We want to make people conscious of the massive production of eggs and all the consequences that this brings."

The ***doings*** shaped by this vison materialize through new plant-based products or new farming models, explicitly paludiculture or vegetable gardening as leisure or part-time activities (Tables 2 and 4). This vision is rooted in ***knowings*** that are highly interdisciplinary and include knowledge from economics, resource management, food technology, politics, architecture, and communication studies. Three founders had prior experience in the food sector, whereas two founder teams included people who were farmers[9]. All startups in which this vision is performed were founded in Berlin.

This vision's ***organizings*** reflect the overall objective of bringing consumers and agri-food systems 'closer together', both at practical and intellectual levels, as a solution to the agri-food issues perceived by the founders. The organizings of urban places, coined by food consumption, and of rural places, coined primarily by the production of agrarian commodities, become dynamic through the vision's doings. The reconfigurations of various value chains partially actively include consumers in field activities or effects on traditional actors in the value chain due to technological or organizational reconfigurations (e.g., fishermen become seaweed farmers or farmers adapt paludiculture farming methods). This is often closely tied to the subject of regionality, reflected, e.g., in the cultivation and usage of local plants to support local ecosystems or short transport routes to minimize emissions due to transportation. The materialization of these reconfigurations has a clear sociospatial expression, as in the case of the active involvement of urban consumers in farming activities, who were previously unfamiliar with agriculture, through microfarms that are close to urban centers, as outlined by the following statement by IP1:

> *"Creating relationships and relations is a very important aspect of sustainability. The people who buy their vegetables from us, they have a relationship with agriculture and food production. They deal with it in a more appreciative way. […] The more people who attend the academy or become [part-time] farmers, the greater the chance that someone knows someone who works in agriculture."*

In addition to the blurring of classic divides between rural and urban places on a more abstract level of attached meanings and experiences, the concrete respective spaces undergo reconfigurations in various ways, including microfarms, urban farming (including the possibility of transforming former public parking lots for this purpose), agroforestry, paludiculture, and 'marine agriculture'.

Vision 2: Partial redesign

Vision 2 *Partial Redesign* is centered on farmers who are eager to use agricultural production methods that preserve natural resources. This vision's materializations, i.e., regenerative farming methods and schemes for the remuneration of nature positive measures, provide the farmers with the means to do so without burdening them with economic losses or bureaucracy. They do not need to adapt completely to new production methods and sociospatial orders, as envisioned in Vision 1. This vision's innovations instead combine traditional farming methods with means that conserve and recover natural resources– a partial redesign. This vision is shaped significantly by the founders' rural–agrarian identity; being farmers themselves, they are driven to safeguard the space-related resources that underpin their businesses and livelihoods. At the same time, this vision is colored by the insights gained outside the industry and away from home.

The vision's ***meanings*** are strongly characterized by the idea that political measures alone might not be sufficient to address the current economic and ecological challenges in the agri-food system and that these measures even have an adverse effect on the relationship between farmers and society. The following statement exemplifies this:

> *"Everything you do that is somehow beneficial to the environment costs money […]. That's why you need other parameters for success on farms that are rewarded. And this should also be done in the private sector and not just through subsidies. Farmers tend to have the feeling they're getting a handout. And society says: You're getting so much money from us anyway, so you have to do it the way we think. And that is a bit toxic. (IP 8)."*

Central to this vision is the idea that farmers' performance, the application of regenerative measures, is worthwhile for them and that this performance needs to be rewarded. In this vision, the meanings are presented in the form of problem frames that consider conventional agricultural methods, such as plowing and the use of agrochemicals, as harmful to the environment, particularly to the soil. Moreover, solutions are not envisioned via absolute organic agriculture; rather, the objective is to create a 'regenerative' agri-food system. The following statement outlines this:

> *"We are relatively critical of the topic of conventional organic farming, which is why we have always placed ourselves with this regenerative approach. And that*

[9] Self-attribution.

means somehow using the best of both worlds"[10]. (IP 10)

These meanings materialize in and are enacted by ***doings*** that are based on market-based incentives for and remuneration of the implementation of regenerative agricultural practices, either through the reward of environmental services or through cost savings, as fewer external agricultural inputs are needed in the field. The doings in this vision aim to enable farmers to use more sustainable farming methods, explicitly through the introduction of more resistant seeds, humus build-up or other nature-positive measures; the last two approaches are combined with and financed through compensation schemes, reflecting the notion that sustainable agriculture needs to pay off.

The vision and its doings are coined by profound ***knowings*** rooted in the founders' personal and professional background in agriculture or horticulture. Two of the related startups were founded in Lower Saxony, and one was established in Berlin, with the latter's founders originating from rural–agrarian regions. Additionally, the founders held economic degrees with a sustainability focus. The convictions that agriculture and environmental protection need to go hand in hand and that traditional agricultural spaces and places need to be preserved, materialize in the vision's innovations that evoke in turn ***organizings*** that leave traditional sociospatial patterns in rural–agrarian spaces mostly unchanged. Moreover, the spaces of farmers and consumers do not mingle. Yet, sociomaterial organizings on the scale of fields change through the vision's doings, impacting rural–agrarian spaces through closed nutrient cycles and more diverse agricultural landscapes with more recession areas for nature, which are characteristics that the vision accumulates under the term 'regenerative agriculture'. Ultimately, through an improvement in soil quality, local value creation increases, along with an improved economic and societal position for farmers.

Vision 3: Optimization of value chains

Vision 3 strongly reflects founders' technological knowledge from outside the agricultural industry, which is primarily used for the optimization of value chains[11]. This vision pursues this optimization through AI-based applications that support human decision-making in the field, which ought to improve resource efficiency and therefore enhance the environmental sustainability of farming methods. Intertwined socioeconomic issues are solely addressed in a superficial but not particularly critical nature.

This vision's ***meanings*** are characterized by the framing that data-based technology could lead to more sustainability in agricultural systems. Ecological sustainability will be achieved primarily by reducing or even completely omitting the use of agrochemicals, which is facilitated by the respective technology. Additionally, the vision is coined by the belief that economic and social sustainability gains can be accomplished through more targeted applications of both substances and labor inputs, with AI providing the necessary data for these optimized agricultural production processes. AI is seen as a facilitator for both environmental and social matter, but not as a threat, as IP 2 notes:

"AI in harmony with nature and humans that is our motto. We develop a technology that supports humans, not replaces them."

These convictions materialize in high-tech ***doings***, primarily in AI-based decision support tools for farmers in the field and sometimes in combination with field robots that, for example, detect plant diseases and recommend further actions to farmers (e.g., which fertilizer to use or when to plant which seeds). Compared with the two prior visions' doings, the application of doings materializing in and through Vision 3 is more flexible and not tied to a specific use case initially articulated through the vision's meanings, opening up possibilities for use by other companies. IP 13 exemplarily describes how their startup works with large agri-tech companies:

"And most of the big ones […] all use our software in their own apps. We did that because we thought, if we also get the images from their farmers, then our competitive edge grows. Because our database is getting bigger all the time. We also supply the big tech companies, agricultural companies with the software."

As these third parties may associate their own norms and values with the vision's material artifacts and thus dilute the vision's original objectives, this underscores that the accompanying meanings and ecological and/or social matters are not as immanent in this vision's doings as in the two prior visions.

This vision's ***knowings*** are rooted in the founders' academic background in STEM fields, with a focus on IT. Prior personal or professional connections to the agri-food sector were only given to a very limited extent. Startups in and through which this vision is co-produced were founded both in Berlin and Lower Saxony.

[10] I.e. conventional and organic farming.

[11] At the time of the interview, the startups' activities focused on preproduction and production. Their future vision also includes processing activities.

The belief in technological solutions to, from the founders' point of view, the most pressing agricultural issues, such as the imprecise use of pesticides or monocultures, as well as their proximity to established agribusiness actors, is reflected in this vision's ***organizings***. Owing to the vision's high-tech artifacts, existing rural–agrarian spaces are organized more sustainably in ecological and economic terms, as data-based technologies simplify crop rotation and intercropping and make monocultures redundant. At the same time, smaller areas are being used for agriculture but in a more intensive yet regenerative and efficient way by using the vision's technological advances, as described by IP 2 as their ideal version of sustainable agriculture:

> *"We would have a ring of smaller farms around cities that work very efficiently in terms of area and use our technology, i.e., the robot plus the monitoring system plus the navigation stack […] plus the decision support tool. […] Without having major labor peaks being able to set up and run a vegetable farm […] on a small area, while supplying the city or a large part of it with regional vegetables."*

With their focus on processes rather than on people, the sociospatial entanglement in this vision is rather a techspatial one, or a sociospatial disentanglement. Consumers do not enter the farming sphere, while traditional farmers are less essential in the fields, as AI decision-making is presumed to be more environmentally friendly. This vision focuses on physical spaces as mere sites of agricultural production; these spaces are not perceived as places that have cultural or emotional significance for people. Although not immanent in the vision's materialization, local value creation should be increased through it, including both the prior production of agricultural commodities and their possible further processing, since long transport routes are associated with unwanted emissions, economic losses, and a negative impact on the quality of transported goods. Thus, agricultural production will move geographically closer to cities. Yet, with high-tech artifacts forming the vision's focus and with many meanings not immanent to its materializations, this vision does not provide a deeper reflection of the sociomaterial entanglement it evokes.

Vision 4: Incremental improvement

Similar to Vision 3, technology is also central to Vision 4. Unlike the prior vision, however, which is characterized by large-scale AI application, the innovations produced by and producing this vision focus on a narrower scale with technical process improvements that address singular parts of the respective value chain, e.g., focusing solely on irrigation, in contrast to decision support and automation throughout the entire lifespan of plants, as in Vision 3 (see Tables 2 and 4), and reflect the founders' expertise and identity, which are deeply rooted in rural–agrarian places.

It is central to the ***meanings*** of Vision 4 that agriculture in Germany, explicitly livestock farming, is regarded as threatened, particularly by legal standards. The continuation of production (e.g., that of livestock farming) in traditional domestic rural–agrarian places and the maintenance of the economic viability of local farms are highly valuable. Here, domestic production is strongly connected to national food security, both qualitatively and quantitatively, which needs to be ensured. In doing so, this vision includes both conventional and ecological farming approaches. The "dismantling" (IP6) of domestic agriculture and its reconstruction abroad, due to rising production costs and requirements, is seen as a multidimensional threat associated with a negative impact on local socioeconomic structures and poor production conditions abroad. Hence, contributing immediately to the preservation of agriculture and livestock farming in Germany is essential to this vision. This is reflected in the vision's ***doings***, which are characterized by the belief that technology can enhance modern agriculture by addressing specific parts of the production chain. These should be made more efficient, whereby inputs, time, and costs are saved, for example, in the case of commodity trading, as outlined by IP 7:

> *"The goal is to develop technology, a software to make buying, selling, and transacting business between farms and their business partners as easy as paying with PayPal."*

The efficiency gains were also connected to the superordinate objectives of modern agriculture, such as enabling faster breeding of new, more resistant crops or improving animal welfare. IP 11 explicitly describes how their innovations can contribute to animal welfare:

> *"[Startup's name] takes care of the animal's well-being in pig and poultry farming through continuous monitoring and artificial intelligence. We use our technology and animal knowledge to help farmers achieve outstanding results because we believe that maximum yield is only possible with and through maximum animal welfare."*

Thus, this vision materializes rather in small-scale applications that should instantly contribute to the preservation of places of rural–agrarian livelihoods in Germany. They constitute easy-to-adapt technical improvements in existing

agricultural operations, which are partially biotechnological in nature and partially combined with AI.

This vision's ***knowings*** strongly reflect the founders' identities and expertise, which is grounded in rural–agrarian places, as they all grew up on these farms, with their parents being farmers. This upbringing resulted in a profound understanding of single production steps, as well as an understanding of the cultural significance that rural–agrarian places have for people living there. The founders' academic backgrounds ranged from STEM subjects to economics and agricultural studies. With one exception, all of these startups were founded in Lower Saxony, with the founder of the urban startup originally coming from a rural–agrarian region as well.

This high identification with rural–agrarian places is reflected in this vision's ***organizings***, which are characterized by a continuation of currently dominant agricultural sociospatial orders. Owing to the vision's technological innovations, these traditional orders are preserved through efficiency gains in terms of cost and time and are characterized by a decreased need for human labor. Additionally, the vision's innovations should help farmers meet modern (environmental, animal welfare, etc.) standards, without their farms being heavily disrupted by innovations due to their incremental character, which makes them easy to implement in existing farming processes. Thus, existing sociomaterial and sociospatial entanglements might be slightly adapted rather than fundamentally reconfigured. Consequently, Germany will continue to be an internationally competitive country for agriculture, including livestock farming. The implementation of the vision's technological materializations will enhance the competitiveness of small and medium-sized farms, ensuring their continued viability and contribution to the broader rural–agrarian socioeconomic community[12].

Discussion

This study aimed to examine agri-startups in Germany through the sociotechnical visions that are formed in and enacted through these actors *vis-à-vis* their sociospatial context. We argue that it is imperative to take a closer look at agri-startups, since they are spurred by a recent surge of financial investment as well as by societal and political hopes to find solutions to the grade challenges of the 21st century. Consequently, it is particularly important to critically scrutinize the agrarian sociospatial reconfigurations they produce and how they relate to broader sociotechnical imaginaries. In our study of agricultural startups in rural and urban Germany, we identify four visions with different understandings of a sustainable agri-food future. The results show that the composition of knowledge (types of knowledge and founders' backgrounds) and meanings (normative framings) fuels the scope and scale of these visions. Furthermore, we find that the visions are sociospatially co-produced. A close-to-farm situation, often due to family ties (reflected in Visions 2 and 4), is linked to the objective of preserving traditional agriculture. Yet, it is not only the nature of the innovations, which should realize this objective, that differ but also the targeted scales (e.g., field, value chain, and societal subsystem) that do (see Table 4). In the following, we first discuss our findings with respect to issues of geography, particularly how visions are spatially co-produced. We subsequently discuss how these visions reinforce and incrementally improve the existing imaginary of industrialized agriculture in Germany before briefly reflecting on the limitations of this study.

The sociospatial embeddedness of agri-startups

Our results show the relevance of geography for understanding the emergence of agri-startups in different sociospatial settings, how these co-produce different innovations and future visions, and how this shapes certain transformative orientations. In this context, we highlight the importance of the factors space and place for agricultural innovation, with various socioeconomic and biophysical drivers being immanent in the sector and forming its economic activities (Pacheco de Castro Flores Ribeiro et al. 2021). Unlike other sectors, which show relative spatial flexibility in terms of locating economic activities and/or entrepreneurship, agricultural activities are largely contingent on physical environments and conditions such as soil, climate, or proximity to markets and infrastructure. Our results suggest that these context conditions and the spatial embeddedness of startups in agricultural settings co-produce their transformative orientation (e.g., rural and agricultural settings reinforcing existing practices compared with urban settings, producing more holistic approaches). This documents the intertwining of visions with place-specific conditions, thus linking to long-standing arguments on matters of place and space for innovation processes (e.g., Sexton 2020; Coenen et al. 2012; Hansen and Coenen 2015). Hence, we argue that innovation processes in agri-startups are not uniform but are spatially contingent and co-produce distinct local meanings, experiences and knowings. Consequently, our study reiterates that future visions are sociospatially co-produced and that physical environments, but also local cultures, norms, worldviews, and networks, matter for innovation processes (Friedrich and Hendriks 2024; Pfotenhauer et al. 2023; Sexton 2020; Longhurst 2015).

[12] This includes, e.g., farms as local employers and farmers as members of local clubs or fire brigades.

Furthermore, our results document that agri-startups are found in both urban and rural contexts in Germany. This highlights the importance of (agri-)startup research across different contexts, which goes beyond a mere focus on cities as the 'only' innovation hub for startups, linking to debates on innovations in 'centers' and 'peripheries'. Linked to this are questions of justice, i.e., whether startups from urban areas may impose their vision and understanding on other places where the resources and material structures for agricultural transformation are located. It is a relevant question for future research to explore whether startups need to adapt to these agricultural contexts or whether they transform them based on the adoption of their products and services in these contexts and what this means for local agricultural communities.

In addition, our research suggests that start-ups are rooted in and focus on different scales. While local culture plays a role, the following section highlights the relevance of existing sociotechnical imaginaries and historically developed power hierarchies that reside at a more collective level of society. This is described in the existing sociotechnical imaginary of agriculture in Germany and the 'iron triangle' (Polzin 2024) and its relevance for understanding startup development. Nevertheless, the 'iron triangle' is particularly spatially embedded in lower saxony and shares social ties with intensive agriculture and livestock farming. Our findings also document different scalar orientations of start-ups, from fields to value chains and sectors. While further disentangling these issues is beyond the scope of this paper, a perspective on the geography of agricultural startups in Germany, as we have attempted to show, can help explain distinct transformative orientations, among others.

Agri-startups perpetuating and reinforcing the dominant imaginary of industrialized agriculture

Our results overlap with those of prior scholarly studies on sociotechnical imaginaries and visions in the agri-food sector in several ways. Fairbairn et al. (2022) demonstrate that despite their seemingly disruptive visions, Silicon Valley's agri-startups tend to offer incremental improvements to existing technologies that do not address complex and entrenched problems in the sector. We also partially identified future agri-food visions co-produced in and through agri-startups (our identified visions *Optimization of Value Chains* and *Incremental Improvement*) that are centered on (high-) tech components that offer technological fixes for specific subproblems but refrain from tackling the deeper social, economic or political problems of sustainability challenges. With these visions' focus on the farm/field scale and on single production steps, where sustainability is to be achieved through improved efficiency, the interconnectedness of different scales or a systemic perspective of agri-food systems is neglected, whereas existing power concentrations, the marginalization of local communities, and the homogenization of agri-food systems are at risk of being perpetuated (Iles and Montenegro de Wit 2015). We attribute this narrow focus to the widespread notion of 'ecological modernization' (EM) within Agriculture Knowledge and Innovation Systems (AKIS). EM is based on the idea that resources must be used more efficiently against the background of both a growing world population and rising resource needs (e.g., for energy and biobased transitions). Among innovation actors, this often translates into incremental adaptations and improvements through technology as a central means of transformation in agri-food systems (Knickel et al. 2017). With respect to our specific case study on agri-startups in Germany, we argue that Visions 3 and 4 are possibly caught in what Polzin (2024) described as an 'iron triangle': a rather impenetrable network of agribusiness actors from the state/politics, science, and industry, which reinforces a corporatist policy style that, inter alia, favors large corporate farms and gives little attention to the downsides of modern farming practices such as environmental degradation and a lack of animal welfare (p. 4 et seq.). Regarding Vision 4 *Incremental Improvement* this occurs rather organically because of its strong sociospatial anchoring in an agrarian rural setting. This is imprinted by the former generation's narrative of 'grow or perish', which is enacted by the iron triangle (Polzin 2024). Hence, Vision 4 sees the only option to sustain the way of life they and their families are accustomed to in incremental innovation that perpetuates existing forms of production through improved competitiveness and efficiency. We share the observation of Friedrich et al. (2022b) that innovation actors in rural, agri-based innovation systems might be less interested in more profound changes, as such changes could undermine their own business models or those of their families or communities. The technological developments co-produced by Vision 4 allow farmers to sustain these sociospatial organizings. Thus, the iron triangle and the sociotechnical imaginary it perpetuates are not overcome but further enforced, manifesting underlying issues, especially the pursuit of further efficiency gains that have put pressure on farmers, animals, and nature in the first place. This 'management of the status quo' raises the question of whether there is an 'over-embeddedness' (Uzzi 1997) of agri-startups that are rooted in ties to the agrarian sector that are too strong. Although they may be equipped with the best intentions, the only difference made by these types of visions might be that it is no longer to 'grow or perish' but rather to 'cope or perish'.

However, traditional agribusiness does not only reinforce itself from within, as the Vision 3 Optimization of Values Chains demonstrates. It is not the actual physical

embedment in either a rural, close to agriculture or urban spatiality, which is decisive for Vision 3, but it is more of an intellectual embedment in a Silicon Valley style of innovating, with its strong belief in tech fixes (Segal 2005), which has recently discovered the agri-food sector (Guthman and Butler 2023). This closeness to the tech sector combined with a lack of embedment in agrarian sociospatial organizings, allows the vision to disentangle from the latter, leading to tech-spatial organizing. In contrast to Iles and Baur (2023), however, agrarian places such as farms are not framed as intolerable places from which humans must be liberated by automation and AI; rather, it is the farms and fields that must be liberated from humans or, more precisely, from their decision-making, in the quest for (a vague concept of) sustainability. Even though the vision was initially formed outside the agri-food sector, it is pulled into the iron triangle by enormous market players that intend to sustain and strengthen their position by working together with startups (Clapp and Ruder 2020; Fairbairn and Reisman 2024) and by politics and science that support high-tech fixes (Rotz et al. 2019; Sullivan 2023; Hackfort 2024).

Overall, these startups risk shifting the power imbalance in the agri-food sector even further in favor of large players, as Heimstädt (2023b) showed, with increasing market concentrations making systemic changes even less likely to occur. Additionally, startups often rely on the existing infrastructure and financial means of incumbent actors to achieve rapid growth (see Fairbairn and Reisman 2024 and Baur and Iles 2023). These power imbalances contrast the arguments of Visions 3 and 4, which emphasize the value and preservation of smallholder farms and the communities in which they are partly embedded. We argue that although there is a technical match, it matches 'too well' with current systems, consolidating and reproducing patterns that have caused the problems these innovations are meant to fix. Miles (2019) also noted this paradoxical observation in the particular case of technologies summarized under precision agriculture. These are often considered revolutionary, solving production problems while contributing to both food security and nature preservation. However, upon thorough examination, it becomes clear that these technologies are rather incremental improvements, as they support and even intensify farming systems that are responsible for various social and environmental problems that precision agriculture is meant to solve. It is a common observation within EM that no (radical) social or political–economic reforms are needed, as the changes emanating from incremental improvements will (cumulatively) lead to sufficient sustainable change (York et al. 2010). This also corresponds with Goldstein's (2018) conceptualization of 'non-disruptive disruption', whereby cleantech innovators, despite fueling promises of a more sustainable future, encounter constraints imposed by capitalistic mechanisms that prioritize profit generation over genuine transformations. As a consequence of their reliance on venture capital, innovators may find themselves compelled to align with the narratives and ideological expectations of investors. This may result in a lack of more radical innovation. This reveals the need for broader consideration and governance of the potential social and economic (unintended) side effects of specifically digital agricultural innovations. In particular, it underlines the need to design governance mechanisms that create the conditions for digital agricultural innovations and their infrastructures to be developed in an inclusive way, i.e., so that a wide range of actors in the agri-food system can benefit from them (Jakku et al. 2023, Zscheischler et al. 2022; Bronson 2019).

Agri-startups moderately challenging the dominant imaginary of industrialized agriculture

We find that more integrative problem frames fuel more holistic visions that challenge existing practices and structures in more substantial ways (see also Friedrich et al. 2022b). Both the visions *Reconfiguration of Sociomaterial Structures* and *Partial Redesign* are co-produced by integrative problem perceptions that highlight different kinds of connections of elements and processes between and within various scales and how these connections shape the functionalities of agri-food systems. By recognizing these inherent complex interactions and (inter)dependencies, Visions 1 and 2 reflect the relation scale's notion that 'the whole is greater than the sum of its parts' (Iles and Montenegro de Wit 2015, p. 487).

The vision *Partial Redesign* demonstrates that startups anchored in agrarian places are not necessarily always 'over-embedded' (Uzzi 1997), as discussed above. Their visions can also imagine transformation pathways that consider sustainability beyond mere efficiency gains at the scale of single production steps and include societal and planetary matters. Vision 2 attempts to loosen the bonds of the iron triangle through so-called 'regenerative agriculture'[13]. The rural, agricultural anchoring of the vision is informed by a holistic understanding of ecological ecosystems that allows for the identification of points of intervention for agricultural practices that not only prevent further degradation of biospheres but also restore them. As Guthman and Butler (2023) argue, "there are biophysical issues that need addressing with biophysical means" to "repair past technological introductions"

[13] We recognize that 'regenerative agriculture' is a fuzzy concept that includes, but is not limited to, the materializations covered in Vision 2, such as minimizing soil disturbance, maximizing soil cover, reducing external inputs, and improving ecosystem services, while tending to touch lightly on the question of the social elements involved (Bless et al. 2023).

(p. 845). However, just like the aforementioned authors, we are reluctant to endorse them without reservations. Being anchored in traditional agricultural sociospatial configurations, the *Partial Redesign* vision explicitly names political and socioeconomic errors in mainstream agri-food systems but co-produces materializations that are rather 'work-arounds' that do not address underlying power and equity issues, a common critique of regenerative agriculture (Bless et al. 2023). Consequently, this vision focuses on farmers whose existence within established sociospatial configurations is to be secured through the application of ecosystem restorative materializations.

However, the most comprehensive changes, as depicted in the vision of *Reconfiguration of Sociomaterial Structures*, are co-produced in and through agricultural startups that originate from urban places. By being both physically and intellectually rather far from traditional agriculture themselves, we argue that urban spaces, to some extent, form what Longhurst (2015) calls an 'alternative milieu', where more countercultural agri-food practices are concentrated and find protected room for experimentation. An ontological and epistemological multiplicity is incisive for such places, as it is reflected in Vision 1 through its diverse knowings and the closeness to consumers, through which the relational scale, the relationships among processes at different scales and between elements across these scales (Iles and Montenegro de Wit 2015), becomes inherent to the vision. We argue that the epistemic and spatial distance the startups of Vision 1 have to traditional agricultural sociospatial organizings facilitates the co-production of this vision. They 'have nothing to lose' and are not deeply anchored in traditional agricultural places (and the iron triangle) as actors of Vision 4 *Incremental Improvement*. Consequently, they can envision more alternative ideas of agriculture that contest the existing sociotechnical imaginary of agriculture in Germany and rhetorically and semantically side with ideas of the 'Agrarwende' (Polzin 2024).

After all, experimenting with new ideas and concepts is considered an important part of sustainability transitions (Sexton 2020; Longhurst 2015; Monaghan 2009). Urban areas may therefore comprise important spaces for experimentation with sustainability-oriented transformations in agri-food systems (see also Zoll et al. 2024 on a related note). Yet, it is to be seen what happens outside this setting, facing the well-coordinated major actors and institutional environments that shape specific innovation strategies, which tend to marginalize alternative perspectives and voices that challenge the status quo (Pfotenhauer et al. 2023). Moreover, the startups in and through which Vision 1 is co-produced do not constitute nonprofit organizations but are dependent upon market mechanisms, which might hamper their diffusion beyond the urban, protected setting. Ultimately, agri-startups co-producing Vision 1 possibly confirm Hilgartner's (2015) assumption that vanguard visions should not differ too much from prevailing imaginaries to be acceptable. In accordance with the basic assumptions of co-production, vanguards tend to redefine and reorganize existing sociomaterial configurations in their respective environments. A complete transformation may not be their overall goal (Hilgartner 2017). However, as a fringe vision, they can challenge prevailing assumptions and limitations of dominant agri-food systems and thus encourage a broader discourse that includes diverse viewpoints and solutions, potentially leading to more robust and inclusive sociotechnical imaginaries (Gugganig 2024).

Study limitations

Our study is among the first to provide empirical insights into the under-researched phenomenon of agri-startups, particularly in Germany (see also Klerkx and Villalobos 2024). As with any research, our study has numerous limitations. First, the in-depth nature of our qualitative study allowed us to consider only a limited number of startups ($n=16$). Therefore, future research may examine the extent to which our types are complemented by other visions and how the distribution correlates with other influencing factors. Second, the identified visions might not seem to differ strongly from each other, as after all, they are produced and enacted by companies that want to have some degree of economic success. More radical visions by startups are likely to fail with the hurdles of resource acquisition and social legitimation (Staber 2005). Given the need of agri-startups for venture capital, deepening knowledge about the network of actors and the network patterns in which they are embedded seems to be an auspicious research direction. But also scrutinizing agri-food visions that materialize through nonprofit actors or in the form of institutional innovations or even exnovations and discussing how these relate to the agri-startup visions appear to be promising future research avenues. Moreover, since we demonstrated that the sociospatial context matters, we encourage scholars to complement and contrast our study with cases from other regions. Thus, complementary insights into actor relationships, possible spillover effects between regions, and how regional innovation networks through which agri-startups venture are constituted and possibly connected remain intriguing research avenues.

Conclusion

Our study aimed to provide a comprehensive characterization of agri-startups, their innovations and envisioned agri-food futures in Germany. We identified four different visions for agri-food systems, revealing different scopes of change. Our study demonstrates that these visions are not 'spatially neutral' but are co-produced by distinct sociospatial settings. The latter finds expression in the respective normative orientation, epistemic origins and material commitments. In two visions, we found a strong notion of techoptimism and digital solutionism, with the main focus on efficiency gains that matches well with the existing sociotechnical imaginary of agriculture in Germany. Our study reveals that this tendency emerges both from a seemingly spatially detached Silicon Valley-style of innovating, and from traditional rural-agrarian places. Yet, both visions are particularly prone to the risk of manifesting various kinds of existing path dependencies, with negative implications for environmental unsustainability. Addressing the more underlying challenges of agri-food systems could rather be found in the first two visions, with one demonstrating that agricultural innovations also evolve in urban settings. However, it remains a topic for future research to investigate whether and how these products and services diffuse, thereby imposing a particular vision of sustainable agriculture on rural and agricultural places that may be characterized by opposing perspectives.

Our research also contributes to the ongoing debate on the prospects of innovative solutions (of startups) in addressing the pressing challenges of the 21st century. It underscores the necessity for a critical examination of the role and expectations placed on startups within agri-food systems. Our results indicate that current startups, despite their seemingly good intentions, reproduce rather than transform the existing imaginary of industrialized agriculture in Germany, which is politically-economically anchored in the 'iron triangle' (Polzin 2024) and spatially embedded in Lower Saxony, among others. Particularly also because investment needs are often met by powerful agricultural actors, who may have little interest in changing the very system. In the pursuit of requisite financial resources, agri-startups may temper their initial principles to align with the ambitions and interests of investors. Therefore, the visions and rhetorical promises of agri-startups should be treated with caution, as startups need to create convincing stories for their products to compete in the 'expectation economy' to attract investment and to materialize. This can lead to visions that are disconnected from empirical realities or that never materialize and calls for a cautious approach to these developments and expectations, as well as continuous evaluation of startups and their actions to critically interrogate their contribution to agricultural sustainability transitions.

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Declarations

Competing interests The authors declare no conflict of interest.

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