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Scenarios for European agricultural policymaking in the era of digitalisation

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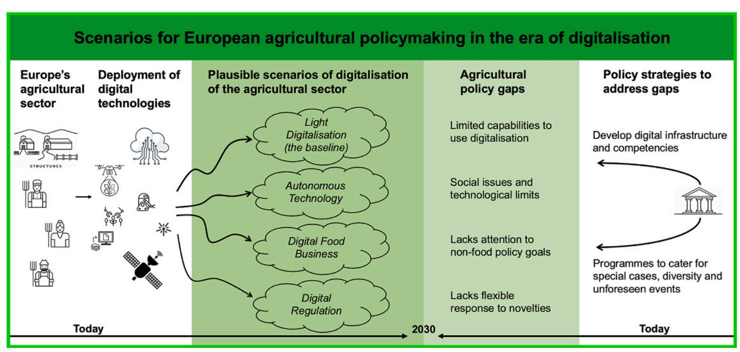
HIGHLIGHTS

- The future for agricultural policy is uncertain, as digitalisation of the sector progresses.
- We develop scenarios of digitalisation of Europe's agri-food sector and derive strategies to address their policy gaps.
- We combine a Delphi study and participatory workshop to develop scenarios.
- Strategies that increase digital competencies, prevent risks and cater for diversity could address policy gaps in 2030.
- This is the first study to derive strategies addressing policy gaps arising in scenarios of agricultural digitalisation.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Digitalisation affects the agri-food sector and its governance. However, what digitalisation of the sector will imply for future agricultural policymaking remains unclear.
OBJECTIVE: The objective of the study is to develop and evaluate explorative scenarios of digitalisation in the agri-food sector of Europe that are explicitly relevant to agricultural policy. The study aims to provide guidance for strategic development of agricultural policy to address the potentials, uncertainties and unknowns arising with digitalisation of the sector.

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METHODS: We combine a Delphi study and a participatory scenario workshop to develop and evaluate plausible explorative scenarios of digitalisation of Europe's agri-food sector. For all scenarios we identify gaps in achieving a range of important European agricultural policy goals, drawing on the Delphi study and desk-based analysis. Subsequently we deduce strategies to address these agricultural policy gaps.

RESULTS AND CONCLUSIONS: Four scenarios of digitalisation of the agri-food sector were developed for Europe in 2030. They comprise of 1) digitalisation of the sector following current directions at current rates as a baseline scenario, 2) strong digitalisation of a regulatory government, 3) use of autonomous farming technology and 4) digitalised food business. These explorative scenarios entail various gaps in achieving European agricultural policy goals. Our findings suggest that the baseline scenario needs strategies to ramp up technological and institutional infrastructure for digitalisation. The other scenarios need strategies to prevent risks, e.g., of technological failures or undesired social impacts. They also need strategies to cater for special cases and diversity, e.g., of ecosystems and farming practices. Across the scenarios, it seems useful to increase digital competencies of the stakeholders.

SIGNIFICANCE: The study is the first that derives implications for policy strategies from explorative scenarios of future digitalisation of agricultural systems that target gaps in achieving agricultural policy goals. The combination of developing and analysing scenarios generated findings that are of significance to policymaking stakeholders and researchers alike, who all need to address the uncertainties arising with future digitalisation of the agri-food sector.

1. Introduction

Digitalisation is a megatrend that also affects the agri-food system. Digital technology can potentially disrupt food supply, farming practices and policy (e.g. King, 2017; Prause et al., 2021; Trendov et al., 2019). Nonetheless, great promises meet grave concerns about future technological risks (e.g. Basso and Antle, 2020; Kuch et al., 2020; Rotz et al., 2019). Moreover, digital technology can change agricultural policy-making itself, as it yields new data and facilitates analysis (Ehlers et al., 2021; OECD, 2019). In addition, new challenges emerge, such as the governance of data sharing (Jouanjean et al., 2020; Wolfert et al., 2017a). Agricultural policy plays a crucial role in achieving a sustainable food system (Davies, 2020; Pe'er et al., 2020). The European Union now expects digitalisation to support sustainability of the agri-food sector (e.g. European Commission, 2020a). Hence, agricultural policy-making stakeholders need to address the uncertainties and unknowns arising with the potentially deep changes digitalisation of the agri-food sector incurs (Rose and Chilvers, 2018). Different pathways on how digitalisation may affect and interact with agriculture need to be explored to align policies to changing conditions of the food system.

This paper develops plausible scenarios of digitalisation of the European agri-food sector. We examine what potential gaps in the achievement of agricultural policy goals arise with digitalisation in explorative scenarios and subsequently investigate what policy strategies can address these emerging policy gaps. The findings of the scenario analysis should make policymaking stakeholders more receptive and capable to address future changes arising with digitalisation of the agri-food sector.

The implications of digitalisation for agricultural policy are an emerging concern that receives little attention in the literature. Recent scenarios of digitalisation of Australian agriculture point at technological, social and economic implications of digitalisation (Fleming, 2021). The scenarios are focused on informing responsible research and development, rather than agricultural policymaking. Responsible research and innovation perspectives (von Schomberg, 2013) themselves increasingly inform research on issues arising from digitalisation for agricultural governance (e.g. Bronson, 2018; Rose and Chilvers, 2018). They call for governance that fosters inclusive design, social responsibility, and sustainability of digital innovations. In this context, agricultural governance can be defined as collective decision making that includes plural actors of the agri-food sector without formal control of their relationships, e.g. through self-regulation via codes of practice (Chhotray and Stoker, 2009; van der Burg et al., 2020). Agricultural policy, in turn, can be defined as the public policy component of agricultural governance that is established and executed by the state, based on formal relationships between policy actors (Chhotray and Stoker, 2009; Jordan et al., 2005). In Europe, which is the focus of our research, government is an important agricultural governance actor, because the Common Agricultural Policy of the European Union and comparable public policies in other European countries are central to the agri-food sector. Even so, recently developed accounts of future agricultural policy (e.g. FAO, 2018; Ferreira et al., 2019) remain disconnected from scenarios of digitalisation in agriculture (Fleming, 2021; Schrijver et al., 2016). Here research lags behind practice. European agricultural policy, for example, aims to achieve its goals through increased knowledge and digitalisation as stated in the Farm to Fork strategy and the Green Deal (European Commission, 2020a).

Scenario analysis supports strategic decision making and allows for 'values-based questioning' of the type of future agri-food sector that is desired. It also facilitates critical reflection on how digital technologies deliver that future (Bronson, 2018). Thus, by addressing future scenarios, policymakers are enabled to align policies to social values and needs (Börjeson et al., 2006). This should not only support responsible research and innovation in agricultural digitalisation, but also help avoiding costly and unintended or undesired impacts of policymaking. However, there is a lack of research on how a specific set of technologies, like digital technologies, could plausibly develop and affect policy-making and future challenges for agricultural policy.

In this paper, we aim to fill these gaps and develop distinct explorative scenarios of digitalisation in Europe's agri-food sector and examine what they imply for agricultural policy. The paper thus addresses a problem of policy relevance through contextualising policy with reference to different futures of digitalisation. We develop explorative scenarios based on qualitative data, because it helps looking into the complex and uncertain future of digitalisation in the agri-food sector that policy making is confronted with. As part of a comprehensive foresight exercise, our approach utilises a participatory scenario development workshop specifically designed for the co-production of knowledge among diverse disciplines (Pohl and Wuelser, 2019; Stauffacher, 2020). To reach our research aims, we take scenario analysis further than usual, as we examine what gaps arise in the explorative scenarios with respect to achieving important agricultural policy goals. These are derived from a preceding Delphi study with the same workshop participants. Our combination of a Delphi study and participatory development of explorative scenarios with a subsequent policy analysis provides practical guidance for strategic development of agricultural policies in the era of digitalisation. It can prevent policymaking stakeholders, such as European governments, from lagging behind technological developments. Researchers benefit from variables to be considered in ex-ante assessments of agricultural policy that concern future use of digital technology in the agri-food sector. Agricultural policymaking stakeholders obtain key anchors that guide development, implementation and evaluation of agricultural policy. They reflect conditions of complexity, uncertainty and data scarcities, within unknown but plausible socio-technical futures of digitalisation in Europe's agri-food sector.

The paper proceeds as follows: we first provide a background on digitalisation in the agri-food sector and on the relevance of scenarios for agricultural policymaking in Europe. A subsequent section specifies the methods of developing and analysing the scenarios. The next section presents the four scenarios, gaps in agricultural policy goal achievement in the explorative scenarios and policy strategies to address these gaps. The implications of these findings for research and future agricultural policymaking are discussed before we conclude with key directions for further research and policymaking.

2. Policy relevance of digitalisation scenarios of the agri-food sector

Europe's agri-food sector changes as the sector deploys digital technologies. To contextualise our study, this section provides background on challenges and opportunities arising with digitalisation in the agri-food sector. It also reflects on the use of scenarios for agricultural policymaking to guide our empirical work.

2.1. Challenges and opportunities arising from digitalisation in the agri-food sector

Digitalisation can imply deep systemic changes in the agri-food sector, beyond mere digitisation of current practice (e.g. Norton et al., 2019; Villa-Henriksen et al., 2020; Wolfert et al., 2017b). Filling a form online instead of on paper would be an example of digitisation, while digitalisation would entail automated generation and processing of the respective data (Parviainen et al., 2017). Relevant digital technologies include invasive as well as remote sensors for crop and livestock monitoring, Internet of Things, artificial intelligence, data analytics and advanced planning and optimisation (e.g. via Farm Management Information Systems) and control and execution of production with help of automatic machines (e.g. for milking) or robots (e.g. for weeding and harvesting). In Europe, advancement, applicability and acceptance of these technologies is fragmented and varies considerably (e.g. Balafoutis et al., 2020; Lokhorst et al., 2019). How this will affect agricultural governance more broadly, including farms, food companies, public authorities and other stakeholders is far from clear. Carefully developed scenarios could structure these uncertainties and unknowns to provide guidance for future-oriented action. Current scientific knowledge on digitalisation in the agri-food sector should provide an important entry point for developing such scenarios.

Besides research on governing the use of digital technology in agriculture, the use of digital technology in public policymaking and new agricultural policy challenges arising from digitalisation of the agri-food sector receive increased attention. A recent OECD report identified and evaluated an array of digital technologies relevant to all stages of agri-environmental policy (OECD, 2019). Novel data generated on farms and in food companies, from consumer behaviour, among others, and big data analytics could help make agricultural policy more effective (Klerkx et al., 2019; Weersink et al., 2018). It emerges that remote sensing and integration of digital databases can improve policy monitoring. The European Union (EU), for example, uses satellite-based earth observation for agricultural area and subsidy monitoring to reduce costly on-the-spot controls, which artificial intelligence can complement (Loudjani et al., 2020). Such uses of digital technology promise better targeting of policy instruments, more effective delivery of desired outcomes and lower implementation costs. While options for agricultural policy increase with digitalisation, they imply critical choices for government, for example on how to allocate responsibilities, costs and participation among stakeholders (Ehlers et al., 2021). To prepare for policy challenges arising with digitalisation of the agri-food sectors not only government, but also other stakeholders involved in policymaking, could benefit from having strategies at hand that address plausible scenarios of digitalisation of the sector.

The expected benefits of digital technologies can also have downsides. Data ethics, including questions of data harvesting, surveillance or transparency of machine learning algorithms, digital skills, social exclusion and set up costs are concerns of digitalisation in agriculture (e.g. Klerkx and Rose, 2020; Regan, 2019; van der Burg et al., 2019). These are also relevant to agricultural policy (Klerkx et al., 2019). Digitalisation could alter occupational roles and identities of agricultural stakeholders who are heavily governed by agricultural policy (such as farmers) (Marinoudi et al., 2021). Overall, the benefits and downsides of digitalisation for agricultural policy seem highly contingent on technologies and institutions and the capabilities of the actors involved (Ehlers et al., 2021). Transferable experience on how digitalisation can play out in agricultural policymaking is limited. Strategic planning of digitalisation of agricultural policy thus needs to cater for uncertain technological and policy futures. Therefore, we use scenario analysis.

2.2. Scenarios for agricultural policy

Scenarios facilitate dialogue between different stakeholders, assist thinking about unpredictable future events, organise uncertainty and complexity, focus attention on a specific problem, raise public and policy awareness on a problem, are launch pads for discussion and communication and can produce options for future action (e.g. Ernst et al., 2018; Godet and Roubelat, 1996; Millett, 1988; Peterson et al., 2003; Riddell et al., 2018). For our research aims explorative scenarios are of great interest as they provide a framework that organises the future consistently for further reflection and analysis (Börjeson et al., 2006). Explorative farming scenarios typically identify driving forces of agricultural futures that are translated into quantified parameters to model scenarios that simulate future environmental, social and economic impacts (e.g. Helming et al., 2011; Mora et al., 2020; Scholefield et al., 2011). We take this further, as we aim to derive strategies for agricultural policy.

Our starting point are scenario studies that explicitly explore technology and policy in a farming context (Rikkonen and Tapio, 2009; Rintamäki et al., 2016). Broader farming scenarios cover general technology and policy variables with little integration (Mitter et al., 2020). A recent study on future farmer profiles suggests digitalisation among the main drivers of farming futures (Krzysztofowicz et al., 2020). Focused scenarios studies aimed at guiding the development of a digital farming decision support system (Dönitz et al., 2020) or at exploring social and ethical issues arising with digitalisation of agriculture to inform research practice (Fleming, 2021). More detailed scenarios of agriculture in the EU explored how precision agriculture and its governance might play out in the future (Schrijver et al., 2016). The scenarios do not focus on digitalisation of agricultural policy as such, similar to a recent scenario study on potential consequences of Covid-19 for the agri-food system (Poppe, 2020). Indeed, few methods of scenario analyses have been developed explicitly to achieve our goal of informing policymaking (Wright et al., 2020, 2013). We build on insights that explorative scenarios can achieve high policy relevance when set up to generate or contextualise plausible policy strategies (Riddell et al., 2018; Svenfelt et al., 2010). Once scenarios are developed they can be explored further to determine policy instruments fitting individual scenarios to meet policy goals (Svenfelt et al., 2010). Such work can uncover lack of policy strategies in current toolboxes to address goals in certain scenarios. It can therefore encourage timely development of alternative policy strategies. Our methods for developing and evaluating scenarios are geared towards these ambitions.

3. Methods: Scenario integration

Our methods build on principles for scenario development (e.g.

Mitter et al., 2019). We designed them to benefit from a participatory approach and to obtain desired outcomes as the development of scenarios progresses (Duckett et al., 2017). They reflect our aims to develop plausible scenarios of digitalisation in Europe's agri-food sector that can inform development of strategies that policymaking stakeholders can use address future challenges in European agricultural policy. The explorative scenarios should present a wide, but balanced range of perspectives and evaluations of uncertain futures. These aims were defined before devising the methods, but could be amended by the experts participating in the study. At the core of our methods is a participatory scenario development workshop, based on "scenario integration" (Fig. 1). It is designed to co-produce knowledge from diverse disciplines and promises to transform broad ranges of perspectives into consistent and tangible scenarios (Pohl and Wuelser, 2019; Stauffacher, 2020). This method is complemented with a pre-workshop Delphi study undertaken with the same participants to build common foundations for the workshop. The findings of the Delphi study establish normative agricultural policy goals that the participants considered important. These goals are at the core of a subsequent policy analysis. Based on the findings of the Delphi study, we analyse and consolidate the workshop findings to make them relevant for practice, comparable to scenario-based strategy development in organisations (Iden et al., 2017). More specifically, we examine the extent to which the same agricultural policy goals are met in each of the different explorative scenarios and what gaps might emerge. We then derive strategies that help stakeholders involved in agricultural policymaking to address these gaps in goal achievement for each explorative scenario. Thus our methodological approach is geared towards developing explorative scenarios that are subsequently analysed with respect to norms that were established externally to the scenarios.

This section provides detail on recruitment of experts, the steps of the Delphi surveys and of the scenario workshop and the desk-based policy analysis after the workshop, as summarised in Fig. 1.

3.1. Sampling experts

For our participatory workshop and Delphi study we aimed for balanced and transparent expert selection (Devaney and Henchion, 2018; Rintamäki et al., 2016). The sampling strategy aspired to select purposefully, in a targeted manner, 'information rich' participants. We focus the sample on academics to have a consistent group of experts that have no commercial interests in digitalisation of agriculture, but knowledge and objective expertise on digitalisation "as a result of unbiased inquiry and exploration"(Devaney and Henchion, 2018). The sampling strategy allows for heterogeneity and breadth within the group of participants. This aligns to a qualitative exploration, where we aimed to gain rich insights and conversations, which are best stimulated by having some commonality in purpose, but sufficient diversity in view, within group discussions during scenario development (Krueger and Casey, 2014). Individual study participants were selected based on their publications and involvement in projects on digitalisation in agriculture in Europe with policy or governance aspects that we identified in preceding desk-based research.

The diversity of participants across gender, career stage and discipline is shown in Table 1. Participants had different areas of specific expertise in digitalisation of agriculture and policy. Overall, the diversity in the participants' expertise ensured the inclusion of broader and more diverse perspectives, leading to the development of a more holistic and comprehensive set of scenarios. The requirement to communicate in English reduced the number of European countries covered (see Table 1). Instead of political scientists, who could not participate, we included two Swiss experts with strong academic background working in government closely linked to research.

3.2. Delphi study

A Delphi study contributed to status quo analysis for developing and

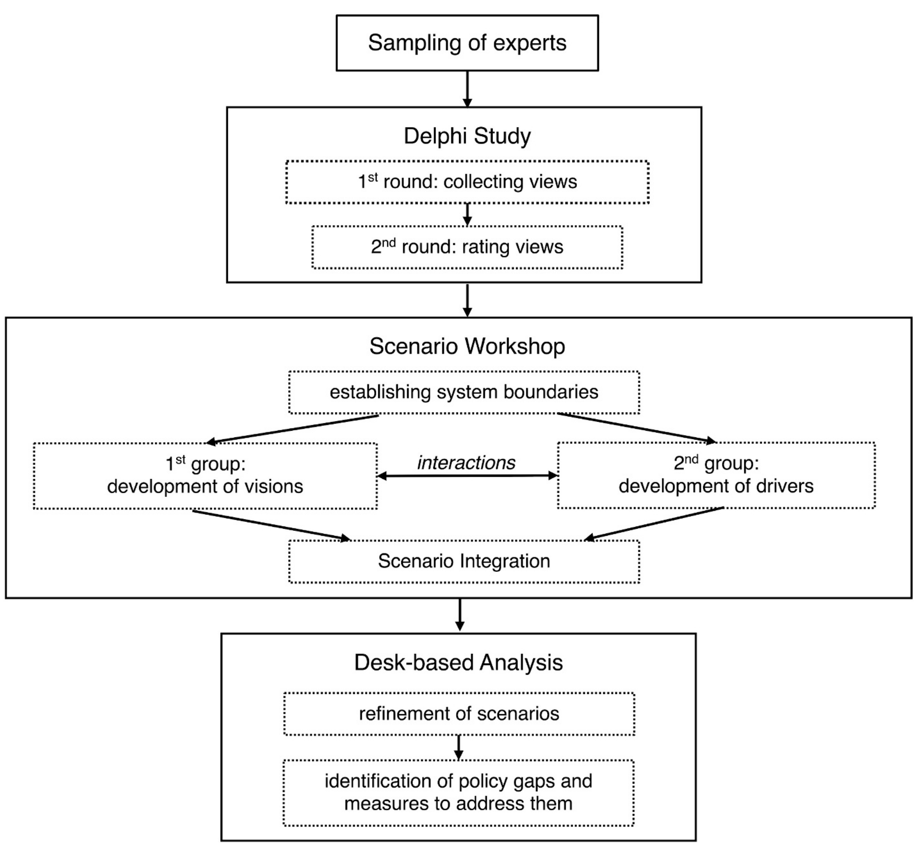

Fig. 1. Steps of the scenario development and analysis method.

Table 1
Attributes of the participants of the Delphi study and the scenario workshop ($n = 13$).

Country	Female	Male	Senior	Junior	Disciplinary backgrounds
Denmark		1	1		Agricultural Engineering
Germany*		2	1	1	Agricultural Economics, Law
Ireland	1			1	Social Psychology
Netherlands		2	2		Information Management, Agricultural Economics
Switzerland*	2	4	5	1	Biology, Agricultural Economics, Geosciences
United Kingdom		1		1	Human Geography

* One senior male did not participate in the scenario workshop.

analysing explorative scenarios. We used two iterations of a Delphi study to prepare the participants for the scenario workshop through establishing common understanding among the participants and first variables to describe scenarios. The Delphi study also generates data on agricultural policy goals and problems in Europe against which the scenarios can be compared (see Padel and Midmore, 2005; Rikkonen and Tapio, 2009). The rating of the policy goals thus directly feeds into the subsequent policy analysis, for which reference points for important policy goals are needed. The remaining ratings of the second round provided context for the policy analysis and summarised views on issues and development of digitalisation in the agri-food sector to initiate group work in the scenario workshop.

We use a Delphi study to enable experts to share and evaluate their views anonymously on a complex topic on which information is limited or conflicting (e.g. Linstone and Turoff, 2011). This reduces social pressure and encourages openness among participants. After each round of questionnaires, responses are summarised by the analysts and fed back to the participants for further reflection or evaluation. Our approach resembles a policy Delphi, as it aimed at uncovering and evaluating broad perspectives, rather than reaching consensus (Rikkonen et al., 2006; Turoff, 1970). The questionnaires were implemented with Limesurvey, ensuring anonymous responses and open and broad inputs to subsequent steps.

The open-ended questions of the first round were developed based on the review of the literature and projects on digitalisation of the agri-food sector and on the role of the Delphi study within the combination of methods we use. They established views on

1) agricultural policy in Europe in terms important policy goals, problems and main drivers influencing agricultural policy;
2) the use of digital technology in European agriculture in terms of important technologies, what influences the use of these technologies and their most important effects;
3) and the role of digital technology in European agricultural policy, including important technologies, what influences their use, important effects and evaluation of future prospects of digitalisation in agricultural policy.

The survey was distributed on 24 May and closed on 2 July 2019 after two reminders. All 13 participants responded. The responses were coded inductively using the software NVivo. Common views were aggregated, where feasible. As codes were mostly distinct and very frequent across responses, we turned them directly into questionnaire items.

For the second Delphi round we used a 6-point scale to transform the coded statements into quantitative scales ranging from very strong disagreement to very strong agreement. Participants could add and evaluate additional statements. They also had to provide reasons for strong agreement or disagreement with statements, using open-ended text. The questionnaire was distributed on 17 July and closed on 22 August 2019 after three reminders with 12 of 13 participants responding. The responses to the quantitative items were ranked from very strong agreement (score 6) to very strong disagreement (score 1) for each question, adjusted for frequencies of 'I don't know' and missing responses. This helps recognising disagreement frequencies, whilst sorting the different strengths of agreement in frequency charts. The open-ended answers were coded, but not transformed into scales. The supplementary material provides more detail on the Delphi method applied.

3.3. *"Scenario integration" workshop*

Eleven of the participants came to Zurich on 4 September 2019 for a one-day scenario development workshop that was facilitated with the "scenario integration" method (Stauffacher, 2020) by a member of the TdLab of the ETH Zürich (https://tdlab.usys.ethz.ch). This method was chosen, because it can capture the broad diversity of views we aimed to bring together and it does not restrict the number of uncertainties initially discussed to two dimensions as the standard two-axes approach does. After a summary presentation of the Delphi study at the beginning of the "scenario integration" workshop, we started with joint definition of system boundaries. Here the workshop facilitators make general proposals, which the participating experts amend, extent and refine. The initial proposals are important to quickly start off the workshop and to provide guidance for further discussion among the experts during the workshop. However, to ensure their ownership of workshop outputs, the experts need to be free to agree on system boundaries, such as the time horizon for the scenarios, among themselves. Next, scenarios are being developed, starting with a collection of an initial set of drivers describing potential scenarios. The workshop continued with parallel work of two groups. One group developed broader visions and the other specific drivers of the scenarios.

Visions and drivers are two complementary concepts to describe scenarios that are mutually adapted to increase comprehensiveness and consistency of the scenarios in the step of scenario integration. Visions are intuitive descriptions of futures that are not restricted by a particular format and can be documented with text and drawings. Drivers, in turn, are specific variables with specific values that describe future states. Each driver is present in each scenario and the scenarios are differentiated through different values of the drivers. The visions and drivers are integrated in an iterative exchange between the groups, with the aim that the drivers comprehensively and consistently describe the broad and informal visions in the end, and to differentiate a limited set of plausible scenarios.

Our approach focuses on developing a set of comprehensive and consistent scenarios that can be described with specific drivers. The scenarios are descriptions of future situations and not of developments. They should be seen as consistent extremes that could plausibly happen, although not necessarily to the fullest extent. This implies that the states of technology and governance in the future year will only be indicative for a scenario and should not be taken for granted. The level of detail developed in our approach fulfils the core aim of the scenarios, *i.e.* to encourage a thinking about the future of digitalisation in the agri-food sector that helps preparing strategies now to meet challenges plausibly arising in the future.

The interactions between the participants in the "scenario integration" workshop included the following steps:

1. The core project team presented proposals to define the system boundaries for the scenarios, including a timeframe between 2030 and 2050, and topical boundaries. Driven by the participating experts they were clarified, further refined and agreed in an open forum lasting three quarters of an hour.
2. A first set of variables that can have certain values that describe the scenarios were collected, called drivers. This was initiated with a brief presentation by a member of the project team of the findings of

the Delphi study on diverse views on future prospects of digitalisation relevant to agricultural policy in Europe. All participants also had a report of the Delphi study and were asked to look at relevant sections. They identified first plausible drivers from the findings of the Delphi study and clarified meanings and discussed plausible values of these initial drivers in an open forum. This step took about three quarters of an hour and included first discussions about missing, redundant and unnecessary drivers.

3. To work in parallel, participants were split into two groups of five and six with equal distribution across gender, career stage and discipline. The first group (drivers group) critically reviewed the drivers as to whether they are adequate to describe the future system of digitalisation in the agri-food sector relevant to agricultural policy in Europe. They could exclude and add drivers. Each driver had to be named and defined, including current values and ranges of future values. They were documented on white board and flipchart. The second group (visions group) was tasked to develop three to four distinct visions of how policy-relevant digitalisation in the European agri-food sector could look like in the future, including a business-as-usual baseline. To achieve a comprehensive understanding of each vision within the visions group the group members where explicitly asked to discuss them intensively. Each vision had to be documented on whiteboards or flipcharts using text and graphics, of which the participants chose both. At the end of this step, each group presented their work to the other group. Open questions were clarified in an open forum. In total, this step took two hours and fifteen minutes.
4. The two groups worked in parallel again. Now, the “drivers group” was tasked to represent the visions developed by the other group with the variables and their respective values making up the drivers. It needed to detect incongruencies between the visions and gaps in the driver-based descriptions. These had to be amended accordingly. The “visions group”, in turn, had to compare the visions with the drivers developed by the “drivers group”. It had to check whether the visions cover variables with different values and are therefore diverse. Important drivers that were seen as missing could be added and their values could be amended to make sure that they fit the visions. Both groups worked separately for two hours, but they could discuss issues with each other, which they occasionally did. The outcomes were documented on whiteboards and flipcharts.
5. Each group presented the revised drivers and visions. These were discussed in a plenary along the following lines: i) What adaptations in the visions are necessary to obtain comparable but distinct scenarios? ii) What adaptations of the drivers are necessary to describe all scenarios adequately? iii) Is the set of visions and scenarios complete or are further ones being required? The visions and drivers had to be adapted accordingly. Agreed adaptations were documented on whiteboards and flipcharts used for documentation of the previous steps. This step took about an hour.

During the integration of visions and drivers in steps 4 and 5, both were iteratively amended to make each other fit. Hence, only drivers fitting the amended visions were selected that best and adequately describe the scenarios (see supplementary material). It was not tried to define causalities between the drivers. Instead, the aim was to identify and amend drivers and values of them that describe the amended visions consistently. This consistency was iteratively checked during scenario integration. The workshop closed with a round of reflection and feedback to the organisers that also determined post-workshop activities.

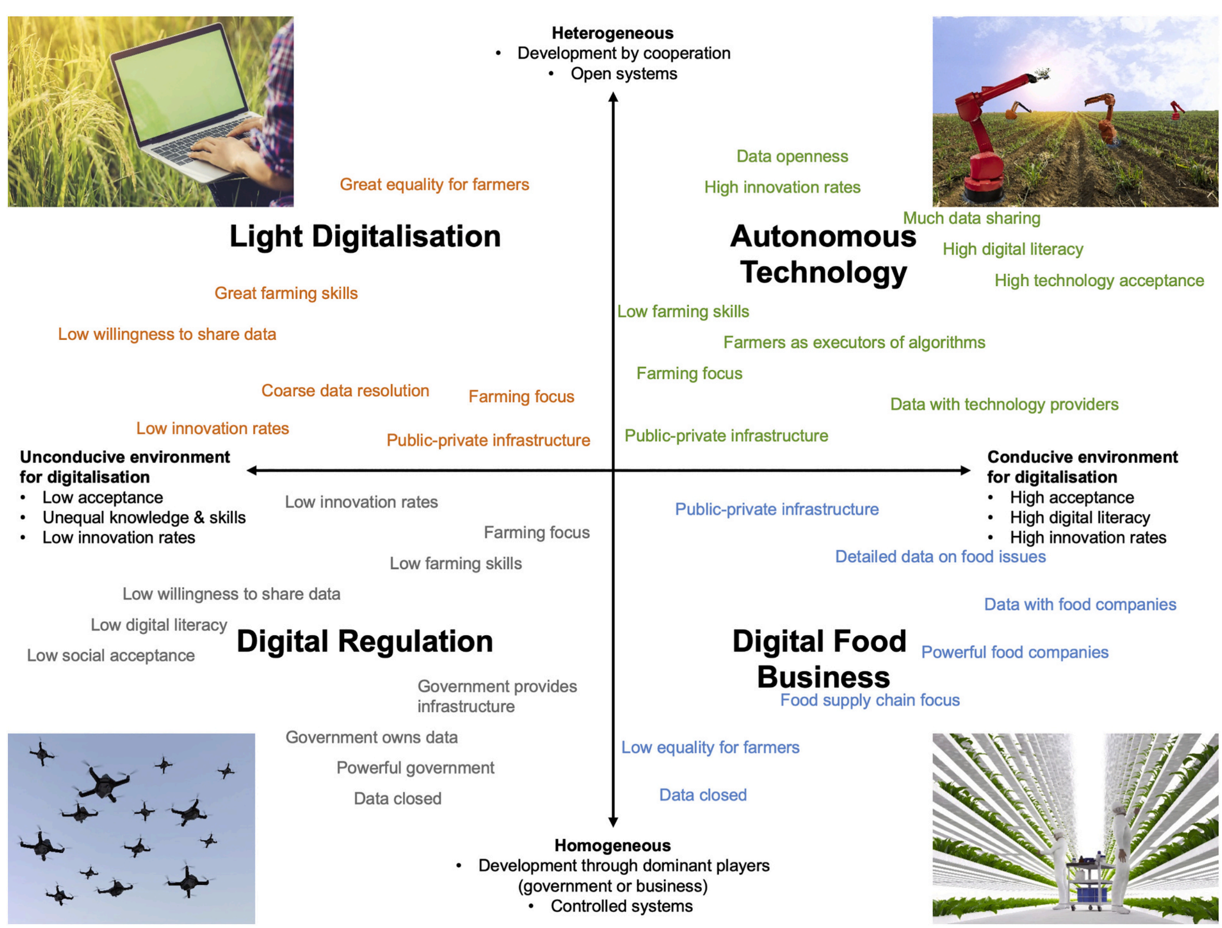

Fig. 2. Four scenarios of policy-relevant digitalisation of Europe's agri-food sector in 2030 ordered according to key dimensions (locations of drivers closer to the extremes of the dimensions imply that their values are more extreme).

3.4. Post-workshop activities

The core project team refined the scenarios using the documentation of the workshop, notes one of the core project members took during the workshop, the Delphi study and further desk-based research to generate consistent scenarios, based on the integrated drivers and visions. The analysis of the workshop material led to a post-workshop summary of the scenarios along two distinct dimensions. The discussions during the workshops indicated the importance of these two dimensions, but they still needed to be fully fleshed out. In addition, two drivers were amended reflecting discussions in the workshop to make the scenarios consistently comprehensive and to better differentiate them. Fig. 2, the tables and descriptions of the scenarios as text, represent the workshop material, but were refined and drafted as part of the post-workshop activities. The post-workshop analysis also identified gaps in the scenarios in achieving the agricultural policy goals established with the Delphi study and proposed suitable policy strategies to address them. These proposals were shared via email with the workshop participants,

Table 2
Four scenarios of digitalisation of Europe's agri-food sector in 2030 relevant to agricultural policy, described with values of drivers grouped in categories.

Category of driver	Driver	Scenarios (described with values of drivers*)			
		Light Digitalisation	Autonomous Technology	Digital Food Business	Digital Regulation
Data and its infrastructure	Data openness	Medium	High	Low	Low
	Data control	Spread across actors	Technology providers	Food companies	Government
	Providers of digital infrastructure	Public-private	Public-private	Public-private	Government
Acceptance	Farmers' technology acceptance	Medium	High	Medium	Low
	Social acceptance	Medium	High	Medium	Low
	Willingness to share data	Low	High	Medium	Low
Knowledge and learning	Farming skills	High	Low	Medium	Low
	Digital literacy	Medium	High	Medium	Low
	Inequality for farmers	Low	Medium	High	High
	Innovation rate	Low	High	Medium	Low
Policy	Policy style	Reactive	Proactive	Proactive	Reactive to proactive
	Dominant power	Farmers and government	Technology providers	Food companies	Government
	Food system perspective	Farm focus	Farm focus	Food supply chain focus	Farm focus
	Spatial and temporal resolution of digitalisation	Coarse	Fine	Fine on food issues	Fine

*The different shades of grey of the cells represent different manifestations of individual drivers across scenarios (light and dark grey are the two extremes and medium grey is a middling value of a driver).

Table 3
Agricultural policy gaps and strategies to address them in the four scenarios of agricultural digitalisation.

Scenario	Gaps compromising achievement of agricultural policy goals	Key strategies to address gaps	Key stakeholders of strategy	Examples of policy goals and technologies involved
Light Digitalisation	• poor digital infrastructure	• crosscutting technological and institutional data generation and exchange infrastructure for policy monitoring and implementation	• government • digital industry	• protecting the environment through digital monitoring of farming impacts
	• limited capabilities of farms to use digitalisation for policy response	• programme to facilitate adaptation of farms to digitalisation	• government • agricultural advisory and education services	• supporting production capacities through user-friendly farm management software
Autonomous Technology	• limited integration of digital technologies	• technological and institutional infrastructure including protocol standards to integrate data from autonomous equipment for monitoring and concerted policy action	• government • digital industry	• providing food along seamless digital traceability systems
	• back-up for risks of autonomous technology	• technological and environmental risk response and prevention	• government • digital industry	• supporting production capacities through offline back-up technology
	• special policy issues autonomous technology cannot address	• programme for special cases	• government	• protecting the environment with help of citizen-science apps and databases
	• lacking attention to social issues, farmers' knowledge and farm-led innovation	• programme to support farmer wellbeing and competencies	• government • farming bodies	• supporting production capacities through farm-led co-production of algorithms
Digital Food Business	• lacking attention to policy goals not in the interest of food business	• parallel programmes for responding to residual policy issues	• government	• providing fibre through integrated databases that localise fibre-based food waste
	• distributional issues and market concentration that disempower farms	• govern issues of mutual public and food business concern, address market concentration and terms of trade of food business vis-á-vis farms	• government • food business	• social support through integrated databases for farmer hardship identification
Digital Regulation	• lacks flexible response to novelties and unforeseen events	• programme for flexible response to emerging and sudden environmental and technological issues such as mistakes in algorithms	• government • where feasible, digital industry	• providing food of needed quantity and quality with help of digitalised supply and demand forecasts
	• non-standard policy issues centralised digital regulation does not address	• parallel programme for special cases	• government • where feasible, digital industry, farming bodies and non-governmental organisations	• ensuring animal welfare with help of digital veterinary exchange service
	• lacks support of innovation	• programme to support capacities of farms to innovate and produce.	• government • digital industry • farming bodies	• supporting production capacities through digital farm innovation hacking portals

who checked their plausibility and consistency, based on earlier versions of Fig. 2, Tables 2 and 3 and the corresponding descriptions of the scenarios in detailed text, drawing on their topical expertise. The suggestions for amendments finally agreed by the group of participants were picked up by the core project team to consolidate the findings.

4. Results

The participants chose to develop scenarios for 2030. From the perspective of the initial situation of 2019, when the workshop took place, it is a timeframe in which digital technology will develop significantly and in which strategic planning of agricultural policy is urgent, hence making the scenarios relevant for policy. It is not a too distant future that leaves technological and policy requirements very uncertain, therefore muting interest in planning. Europe was defined as the geographical boundary. Within these system boundaries the participants developed four scenarios. They are based on the integration of several visions of digitalisation of agriculture relevant to agricultural policy and drivers describing them. This section first introduces core features of the scenarios with help of two cross-cutting dimensions. Then we compare the scenarios in detail and provide richer descriptions. The final part covers the gaps in achieving agricultural policy goals in the scenarios and strategies to closing them.

4.1. *Cross-cutting dimensions of the scenarios*

All developed scenarios of digitalisation of the agri-food sector are relevant to agricultural policy. They can be differentiated along two dimensions: 1) whether digital technology faces an environment which is conducive to its deployment or not and 2) whether technologies and institutions are heterogeneous or homogeneous. The four quadrants of Fig. 2 accommodate corresponding attributes of drivers. The values of the drivers are relative to another and not relative to the initial situation in 2019. They represent the scenarios along these two dimensions and reflect the ranges of values of drivers of the scenarios compared in Table 3. The two dimensions are only key dimensions, while the drivers and their values in Table 3 differentiate the scenarios in more detail. Environments are conducive to deploying and advancing digital technology when actors are literate enough to use and develop digital technology. Moreover, institutions such as legislation and social norms governing acceptance of digital technology in society at large (social acceptance) or among farmers support use and innovation of digital technology. Heterogeneity of technologies and institutions means that there are several and different technological options for digital technology and diverse public, cooperative and private institutions involved. They include proprietary and open digital systems, for profit and non-profit enterprises. Homogenous institutions and technologies cover single dominating digital technologies, standards and social norms, and single dominant actors, such as monopolistic enterprises and government units.

The *Light Digitalisation* scenario reflects the need for a dynamic baseline in which digital technologies are present and develop at rates and in directions of current developments. Hence it extrapolates developments in the initial situation of 2019 to 2030. This scenario consists of an environment not very conducive to using digital technology. Heterogeneous technologies and institutions include open systems and cooperation, which the scenario shares with the scenario of *Autonomous Digital Technology*. However, the latter scenario is based on an environment that is conducive to deployment of digital technology. Characteristics are high innovation rates and digital literacy of the actors involved. This also characterises the scenario of agriculture dominated by *Digital Food Business* which, in turn, is more homogeneous, because digital systems are controlled and concentrated in the hand of dominant actors. Similar dominance can be found in the *Digital Regulation* scenario in which agricultural policy is executed digitally in a regulatory state. It operates in an environment in which digital technology lacks support through digital literacy, while acceptance in society and by farms is low. What the participants found to be impacting in detail on the four developed scenarios is described in the next section.

4.2. Drivers

The stepwise identification, definition and selection of drivers helps to develop distinct scenarios, especially as they can be differentiated according to the values attached to the variables making up the drivers describing the scenarios. Table 2 shows that the scenarios consist of a broad range of drivers, which can be grouped into drivers 1) describing data and infrastructure, 2) degrees of acceptance, 3) knowledge and learning and 4) policy issues. The scenarios differ according to what values the drivers have. As a result of post-workshop analysis, a driver was added to specify who provides digital infrastructure and the "power of retailers" driver was amended to "dominant power" to capture power distribution among all key actors involved. This reflects findings of the Delphi surveys (see supplementary material).

The individual drivers are highly aggregated. For example, they do not differentiate between data coming from farms and data coming from consumers via food companies. The drivers also relate to another. Social acceptance and acceptance among farmers relate, for example, to digital literacy and power. Such nuances of the scenarios are developed in more detail in the descriptions below.

4.3. Detailed scenario descriptions

Combined with the description of the visions, the values of the drivers describing the four different scenarios in Table 2 form key ingredients for more extensive descriptions of the scenarios. The differences remain apparent, although these descriptions provide richer and more nuanced pictures of the scenarios. Ultimately, the descriptions cover a broader range of plausible scenarios as the generally positive answers to the final question of the Delphi survey on the future prospects of digitalisation in agricultural policy suggest. They still pick up contingencies of future digitalisation in the agri-food sector on institutions, infrastructure, knowledge and technologies used.

4.3.1. Light digitalisation

In this baseline scenario, digitalisation and agricultural policy represent current developments. Data control is spread across the sector. Farms control data and supply it to government and business where they see fit. Government needs to respond with incentives for farms to disclose data that supports agricultural policy. Data on consumers generated by agri-food companies does not feed into agricultural policy and rarely into farm management. Some companies generate data from farms, which rarely feed into agricultural policy. Openness of data depends on policy issues, because government and the farming sector negotiate data access within the bounds of policy issues. Government uses remote sensing and environmental monitoring data acquired from outside farms.

Willingness to share data is low, unless sharing has some direct benefit, for example, to farm management. This varies with policy issues and involvement of algorithms. Social acceptance and acceptance among farms and business is restrained, as the extent of digitalisation of agricultural policy changes only gradually.

Digital literacy and adoption of digital technology are unequally distributed within single groups of actors and among actors such as farms, farm input and food companies and advanced specialists. Skills in using digital technology of policy relevance increase, despite co-existence of analogue alternatives. Industry informs farms more extensively on digital technologies than other actors. Rates of innovation in policy-relevant digital technologies are low among all actors.

Power distribution in agricultural policymaking remains unchanged. Agri-food companies are powerful, also in using digital technologies of relevance to agricultural policy. Digital technologies are rare and not dominated by new actors. Top-down (agricultural) policies focus on farms and change in reaction to issues that are driven mainly by farms. Negotiated, but limited farm data access allows some policy adjustment to local circumstances and better achievement of environmental, food quality and animal welfare policy goals. Infrastructure needed for using digital technology in agricultural policy is both public and private. As it is not very extensive, it limits the scope and speed of digitalisation.

4.3.2. Autonomous technology

In the autonomous farming technology scenario, the farming systems are automatically sharing data and communicating digitally. Digital technology and algorithms that solve environmental, food safety and animal health and welfare issues drive the farming sector. They include robots and algorithms that replace work and provide the knowledge for decision-making on farms. As data are open, all actors, including farms, tech and food companies, government and consumers, share data. Nonetheless, farmers become mere executers of capital-driven algorithms that utilise big data. Production data has value and companies link consumer data to farming technologies.

As data are critical for successful operation, for example via system optimisation, the willingness of all actors to share data and to use technology that facilitates data exchange is high. Acceptance of digital technology is generally high in society, but less consistently among farmers. Business accepts autonomous farming technology, where venture opportunities arise. Government shows acceptance, where it can utilise the algorithms and data, but struggles to be in control of the technologies.

Digital literacy is skewed. Farmers are less able to influence digital technologies than fulfilling commands of technologies. They learn how to execute digital commands, where no autonomous devices replace them. Digital technology quickly adapts to local circumstances and increasingly steers generation of information. Open data and transparent value chains level the playing field for businesses and increase innovation rates.

Under the power of digital technology farmers become mere executors, while government cannot keep pace. Nonetheless, policy measures protect autonomous farming. Algorithm-driven targeting of policy implies that agricultural policy becomes embedded in technology. It is proactive to the extent government gains access to data and algorithms identify policy issues through predictions grounded in the data generated. Agricultural policy faces goal conflicts regardless, including conflicts between farmers and algorithms. Private companies and government, who share great interest in successful operation of autonomous farming, provide digital infrastructure.

4.3.3. Digital food business

Digital business models of dominating food companies driven by consumer data control farm data to the extent it matches their consumer orientation. Farms share production data with these companies, consumers and government and therefore become very transparent. As consumer data are a critical resource for food companies they are more tightly protected. Governmental data access regulation is limited, because the food tech companies are stronger players, but government can access data that does not interfere with food companies.

Although willingness to share data is generally low, food companies force others, like consumers and farmers, to share data of their interest.

Acceptance of the digital technologies involved is high among food companies, as they benefit most from these arrangements and among consumers, because the food companies align consumers with their interests. Disadvantaged businesses and farms show little acceptance. Government shows great acceptance, where it can access data for its own purposes. Nonetheless, the more food-related an issue the more government depends on food companies and its acceptance is lower.

Digital literacy is very high and concentrated in food companies. They also show high but narrowly focused innovation rates. All other actors have lower digital literacy and innovation rates.

Power distribution is highly skewed towards food companies that dictate distribution of added value. Government greatly depends on them. Agricultural policy focuses less on farm activities than on food companies as they govern farming very closely. Agricultural policy does not target individual farms. Its policy measures are restricted to residual issues that food companies do not influence. These companies regulate how food is being produced, which becomes the main policy concern, because consumers are geared towards it. Policy in the interest of food companies is proactive, reflecting predictions based on their data. Remaining policy just reacts to emerging issues. Food companies also provide and manage the key digital infrastructure in their interest. Public funds support the infrastructure due to their lobbying.

4.3.4. Digital regulation

In the digital regulation scenario digital technology is used extensively, but it is government-controlled. Farmers are forced to supply data of relevance to agricultural policy to government, which uses these data extensively in traditional agricultural policy fields. Consumer data is mainly held by agri-food companies, although government controls the governance of data. Hence, government also defines and implements data access in its favour.

While farms have low willingness to share their data, government enforces data sharing against their will. It uses data analytics and algorithms for decision making where they support its agricultural policy interests, reaching deeply into farms to make them transparent. Farms show little acceptance for this approach, because non-compliance is punished strictly, and their data is very transparent. Government strongly accepts the approach, as it helps optimising agricultural policy. Social acceptance is generally low, because technocratic digitalisation of agricultural policy stifles public participation and infringes widely shared values of privacy.

Core digital knowledge and skills are within government administration and lower for other actor groups. Public extension, technology design and obligations for farms and other actors to use digital policy technologies force development of respective skills for agricultural policy purposes. Agri-food businesses facilitate use of governmental digital technologies, when having interest in farms complying with policy requirements. Innovation rates are only high for digital technologies that government uses for agricultural policy and for technologies that support farms to respond to government. They quickly diffuse in the sector. Farms not using them are penalised and likely to disappear.

Government reduces and equalize the power of all actors to engage in agricultural policy, because it controls digital technology used for agricultural policy. The technocratic policy approach implies that agricultural policy needs to conform the digital technologies of government and that policy change only comes from government. It predicts agricultural policy issues strategically and addresses problems immediately when they emerge, because failure to do so suggests that its digital technologies are not superior. Government provides and manages all necessary infrastructure for using digital technology to ensure ability to execute agricultural policy in its interest.

4.4. Agricultural policy gaps in scenarios of agricultural digitalisation

Our assessment of the extent to which agricultural policy goals are achieved in the scenarios suggests that gaps in goal achievement depend less on the specific goals rather than on key characteristics of the scenarios. The Delphi study identified a range of important agricultural policy goals for Europe (see supplementary material). They can be summarised as providing food, protecting the environment, ensuring animal welfare, supporting production capacities, social support and providing fibre. Table 3 shows that the specific gaps in achieving the goals vary in the scenarios. The gaps and suitable measures to address them strongly relate to the degree of technological and institutional heterogeneity and the degree to which environments are conducive to utilising digital technology. They differentiate the scenarios in Fig. 2. Each scenario has a different combination of extremes of the two dimensions and respective gaps in achieving important agricultural policy goals: a scenario may, for example, not cater for social and agroecological diversity or it lacks technological and institutional (including organisational) infrastructure that is conducive to achieving goals. Thus, distinct implications for agricultural policy arise for each scenario that entail specific tasks for policy stakeholders.

With the exception of the baseline scenario of *Light Digitalisation*, policy needs to have strategies that run in parallel to the digitalised governance that characterise the scenarios. Then it is able to address emerging policy gaps. These gaps concern social issues and response to non-standard demands and novelties. Generally, the public policy strategies need to complement and fit to the characteristics of each scenario. Thus, policy strategies in the *Light Digitalisation* scenario should largely resemble current practice and can serve as a starting point. This scenario needs policy to improve digital infrastructure to better achieve agricultural policy goals. Such improved infrastructure could prepare ground for the *Digital Regulation* scenario to emerge. If this is not desired, preventive measures are needed. In the *Digital Regulation* scenario strategies would largely be top-down technocratic approaches, although parallel programmes could experiment with alternatives to some extent. The *Autonomous Technology* scenario, in turn, would require policy strategies that allow negotiation and cooperation with agri-tech providers and more distributed and decentralised approaches. The *Digital Food Business* scenario, too, would require an approach based on negotiation and cooperation, this time with food companies. For the residual issues in this scenario traditional policy strategies should suit.

The scenarios dominated by digital and food industry share in common with the *Digital Regulation* scenario a need of public policy to attend to special cases and to cater for diversity and farmer-led innovation. Hence, improving digital infrastructure and competencies of the stakeholders seems to be wise general strategy for agricultural policy in an era of digitalisation. A complementary strategy is to maintain or even boost ability of agricultural policy to respond to uncertain events, special cases and diversity.

5. Discussion

Our combination of a Delphi study, participatory development of explorative scenarios and a subsequent policy analysis allowed to meet our research aims, *i.e.*. to derive strategies for policymaking that help addressing future gaps in achieving agricultural policy goals that can plausibly arise with digitalisation of the agri-food sector. In the following we first discuss the content of the scenarios with respect to research on current developments in digitalisation of the agri-food sector. Next, we discuss the scenario analysis methods with respect to our aims and relating studies as well as the use of scenarios studies such as ours in addressing uncertain futures. We also discuss the policy relevance of the scenario analysis and its time horizon and implications of our sampling strategy. Finally, we address implications of our findings for agricultural policymaking and its stakeholders as well as research and innovation and scenario modellers.

The explorative scenarios we developed point systematically at contingencies of outlooks and evaluations of digitalisation in the agri-food sector. This can aid development of context-sensitive policy strategies. The literature suggests more transparency and data on food supply and environmental impacts and increased efficiency as typical benefits of digitalisation (e.g. Finger et al., 2019; Kos and Kloppenburg, 2019; Weersink et al., 2018). These feature in all our scenarios, except the baseline scenario. However, the benefits do not concern all stakeholders equally. Problems are often connected to distributive consequences. They include replacement of farm labour and erosion of knowledge by machines (Carolan, 2020; Marinoudi et al., 2019; Miles, 2019), as in our *Autonomous Technology* scenario, and privacy corruption and control of farming by big food and tech business (Fraser, 2019; Kos and Kloppenburg, 2019; Prause et al., 2021; Rotz et al., 2019), as in our *Digital Food Business* scenario. Developments resembling our *Digital Regulation* scenario receive little research attention. Studies evaluating digitalisation in agriculture usually imply just one scenario that logically derives from the analysis. They usually consider a very limited set of variables. Our application of scenario integration generated a range of scenarios of digitalisation, based on multiple variables. Such approaches could prevent anticipation of just one future of policy-relevant digitalisation in the agri-food sector to which current policy and practice aligns (Carolan, 2020).

Our approach is broader than standard scenario analysis in two ways. First, the Delphi study generated common understanding and context for the scenario development and the policy analysis. Second, the “scenario integration” method allows to comprehensively transform insights from diverse disciplines into consistent and tangible scenarios (Stauffacher, 2020). The method yielded four scenarios that can be differentiated along two dimensions of uncertainties, which emerged from the material generated in the workshop. The dimensions were not conceived before the start of the workshop, as in the traditional two-axes approach (e.g. Fleming, 2021; Westhoek et al., 2006). While our approach identified a range of drivers that can describe the views comprehensively and consistently along our scenarios, we did not aim for establishing causalities between them. Future research might aspire to develop a set of drivers and establish causalities between them. Other scenarios of digitalisation and farming futures based on methods comparable to our application of scenario integration help to situate our findings and to identify avenues for further research. Following the framing of future digitalisation in Pansera et al. (2019), the scenarios of *Digital Regulation* and of *Digital Food Business* would be unwise, because of centralisation of power and control. The scenarios of precision agriculture, developed by Schrijver et al. (2016), raise such risks associated with monopolies and inequality, alongside stricter regulation and extensive automation of farming. The policy strategies derived for them are not yet linked to policy goals. Instead, Schrijver et al. (2016) suggest policy options to address concerns arising with the technology. In this context, the policy analysis of the explorative scenarios helped establishing policy strategies to address gaps in achieving agricultural policy goals. The scenarios themselves are explicitly not normative and do not contain policy goals. Hence, we can examine how a set of given policy goals is achieved in each scenario and derive strategies to address gaps in goal attainment that can both cut across and be specific to individual scenarios.

Like a scenario analysis for Swedish environmental policy (Svenfelt et al., 2010), our study underlines the need to address uncertainty and nurture diversity in longer-term policy strategy. These issues receive surprisingly little policy and research attention, despite their importance for farm viability and decision making (e.g. Buitenhuis et al., 2020; Chavas and Nauges, 2020; Severini et al., 2017). Approaches of post-normal science could inform such research, as they explicitly pick up uncertainty and futurity (Funtowicz and Ravetz, 1993; Turnpenny et al., 2011). Here our participatory scenario integration is a first step towards systematic exploration of how agricultural policy can respond to uncertainties and ambiguities arising with digitalisation. Further research could investigate abilities of different types of farms to respond to scenarios of policy-relevant digitalisation in the agri-food sector and evaluate resultant socio-economic impacts. Actively anticipating, and attending to, these potential impacts at early stages of policy development supports the goals set out for responsible research and innovation (Fleming, 2021; Stilgoe et al., 2014).

Agricultural policy in Europe shapes the adaptive capacity of farms, which is why anticipatory governance will be a critical for ensuring socially acceptable policies for digitalisation and agriculture (Barrett and Rose, 2020). Our application of the scenario integration method is one approach to facilitate such anticipatory governance. Personal judgement and relationships of the experts constructing our scenarios could have influenced desirability of our scenarios. This was shown for rural development scenarios (Metzger et al., 2010). The identification of policy goals and gaps in our scenarios is separated from the scenario development, hence mitigating bias. Our scenarios also do not aim at suggesting effects of agricultural policy on outcomes (e.g. Helming et al., 2011). Instead, we explore how policy could address policy gaps under different scenarios. These cover a broad range of plausible futures similar to other agri-food scenario studies (e.g. Mora et al., 2020; Rikkonen and Tapio, 2009; Rintamäki et al., 2016). Our scenarios consider the time period up to 2030, which is a time horizon similar to other scenarios covering digitalisation in agriculture (e.g. Dönitz et al., 2020; Fleming, 2021; Schrijver et al., 2016). Agricultural technologies can spread rapidly in the timeframe, as history has shown (e.g. De Clerq et al., 2018; Rogers, 2003; Settele, 2018). The horizon for current reforms of the Common Agricultural Policy of the EU underlines the policy relevance of the timeframe as do the expectations to use digital in agricultural policy implementation (European Commission, 2020a; European Court of Auditors, 2020; Loudjani et al., 2020). Our results imply that European policy stakeholders need to prepare strategies to address digitalisation, even when underlying technology could be more widespread at later points in time.

The tendency of our participants to agree greatly with the agricultural policy goals in line with current public sentiment in Europe (European Commission, 2020b) might suggest a less productive policy Delphi (Linstone and Turoff, 1975; Rikkonen et al., 2006). Great agreement could also suggest biased viewpoints, for example because researchers who are involved in digital technology dominate our sample. The participants reflected diversity of academic discipline, gender, and career stage. An even more diverse group of participants beyond academia and methods geared even more towards disaggregation of viewpoints might have led to more extreme evaluations (Rikkonen and Tapio, 2009). The rather narrow focus on academics from western European countries facilitated efficient development of consistent scenarios. A caveat of the sampling strategy could be the lack of diversity of perspectives in our scenarios. This might have impacted on the development of scenarios considered plausible and the rating of important goals of European agricultural policy. To compare our findings in a different context, future research using similar methods could draw on a broader sample of participants, including other nationalities and professions.

Our findings also underline that governments in Europe are key stakeholders of both agricultural policy and digitalisation of the sector. The agricultural policy gaps we identified for the four different scenarios of digitalisation in the agri-food sector and the strategies to address them call for government to engage in planning respective measures and building competencies. This engagement is urgent for the EU and member states governments as the EU's Farm to Fork strategy and the Green Deal currently push for increased digitalisation of the agri-food sector and policy (European Commission, 2020a). Slow or late engagement of European governments in developing respective strategies could make it harder to reach agricultural policy goals. To what extent this is also the case for governments in other parts of the worlds cannot be answered within the scope of our study, but governments can certainly have similar roles when their goals match European agricultural policy goals. Future research could develop scenarios that are more relevant for specific settings in other parts of the world and help formulating strategies that address future agri-food governance challenges arising with digitalisation in these contexts. Implications from our scenario development that are less dependent on specific policy goals arise for other policymaking stakeholders too and may well apply outside Europe. These implications both cut across and can be specific to scenarios and specific to particular subsectors. All policymaking stakeholders are well-advised to evaluate whether their current strategies are appropriate for all or several scenarios or only meet requirements of a single scenario as listed in the previous section. The different scenarios suggest distinct opportunities and roles for agri-food business that companies could consider when developing their strategies. Non-governmental organisations should evaluate the extent to which their concerns are affected in the scenarios of digitalisation in the agri-food sector and lobby respectively. They could also consider building the skills needed among their constituents to deal with relevant digital technology. Farm businesses are generally well-advised to develop digital literacy and to examine whether new practices and technologies they plan to use fit digital technologies used in future agricultural policy. Their options are certainly constrained by the digital technologies available in each scenario and their user-friendliness. Technology providers should therefore carefully plan and develop suitable digital technologies that meet the needs of other stakeholders arising in the future. Science stakeholders, advisory and industry bodies should strive for collaborations with farmers and civil society stakeholders in inter-disciplinary and multi-actor approaches to help all stakeholders to meaningfully address the policy challenges that arise in the different digitalisation scenarios (Kernecker et al., 2021; Rijswijk et al., 2019).

Digital technologies need to be tested and validated in all scenarios to prove functionality and improve their quality such as compatibility and interoperability and trust in the digitalised systems. Dedicated infrastructure, programmes and approaches, such as user-centred design, can facilitate here and help ensuring that digitalisation in agri-food sector does not compromise agricultural policy goals. The EU subscribed to Responsible Research and Innovation to achieve such ends (Owen and Pansera, 2019). Our findings suggest that it also needs to be built into agricultural policy and particularly into its newly emerging branch of agricultural digitalisation policy.

Finally, most descriptors of our scenarios could be important inputs to modelling. Data availability is likely to constrain the use of our scenarios as input for the modelling agricultural policy impacts (e.g. Paloma et al., 2013). However, data on digitalisation should increase, when stakeholders address the policy gaps we identified. Moreover, the drivers describing the scenarios, policy goals and gaps can serve as model assumptions.

6. Conclusion

The prospects and effects of digitalisation in the agri-food sector and in agricultural policymaking are uncertain. To prepare agricultural policy stakeholders in addressing uncertain future challenges arising with digitalisation, we developed four scenarios of policy-relevant digitalisation of the agri-food sector. Gaps with respect to important European agricultural policy goals are identified for all these scenarios. These are used to derive measures that address deficiencies of policy performance in the scenarios. Our findings therefore assist policymaking stakeholders in developing cross-cutting and specific strategies to tackle challenges in scenarios of policy-relevant digitalisation of agriculture.

A key implication of our scenario analysis for policymaking is the need to strategically develop digital infrastructure for agricultural policy. This is not surprising and fits current research. Our analysis suggests that developing digital infrastructure is fundamental to any scenario of policy-relevant digitalisation of agriculture in Europe and it helps to lift the benefits of digitalisation in achieving policy goals. However, it is important to always examine what undesired impacts on agriculture and the food system could emerge from digitalisation. The limits of digital technology also need to be identified. They vary among the different scenarios. Policy strategies addressing these limits and undesired impacts often need to be developed and trialled in advance. They also need to fit scenarios. Hence, it is worthwhile to build respective competencies, institutions and resources early on, both in government and among agricultural policy stakeholders. Finally, it is important to develop flexible strategies. They should allow diversion from digitalisation and policymaking pathways, considering the uncertainty about which scenario will most likely prevail.

More detailed insights into how agricultural policymaking could respond to the use of digital technology in the agri-food sector is still required. Our scenarios could be enhanced through further technological perspectives and viewpoints of governance and public administration experts and wider ranges of stakeholders including farmers. Drawing on such expertise could broaden up the scenarios and add detail. Ongoing developments in digitalisation and agricultural policy could lead to different visions of digitalisation of agriculture and of agricultural policy goals in the future. Agricultural policymaking should take the broad range of plausible futures of digitalisation of the agri-food sector our research suggests into account. Technological developments and path dependencies of policy-relevant digitalisation need to be assessed too. This could follow a Responsible Research and Innovation perspective at more detailed scale, which our scenarios and agricultural policy goals could inform. We assumed agricultural policy goals and their importance to be stable, but closer monitoring of policy preferences and their institutionalisation in European agricultural policy making seems useful. Our analysis of the scenarios identified a need to cater for uncertainty and diversity in longer-term agricultural policy strategy. This receives surprisingly little research attention and could be informed by post-normal science research. Likewise, research on the limits and scope of farms to respond to scenarios of policy-relevant digitalisation of the agri-food sector is still missing.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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