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Impact of Covid-19 on farming systems in Europe through the lens of resilience thinking

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HIGHLIGHTS

• Comparison of pre-Covid-19 findings and Covid-19 crisis
• All systems displayed adequate agility to activate coping capacities.
• The crisis triggered reflexivity about the operation of the farming systems.
• Transformative capacities were not observed.
• The systematic resilience assessment revealed system vulnerabilities.

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ABSTRACT

Context: Resilience is the ability to deal with shocks and stresses, including the unknown and previously unimaginable, such as the Covid-19 crisis.

Objective: This paper assesses (i) how different farming systems were exposed to the crisis, (ii) which resilience capacities were revealed and (iii) how resilience was enabled or constrained by the farming systems’ social and institutional environment.

Methods: The 11 farming systems included have been analysed since 2017. This allows a comparison of pre-Covid-19 findings and the Covid-19 crisis. Pre-Covid findings are from the SURE-Farm systematic sustainability and resilience assessment. For Covid-19 a special data collection was carried out during the early stage of lockdowns.

Results and conclusions: Our case studies found limited impact of Covid-19 on the production and delivery of food and other agricultural products. This was due to either little exposure or the agile activation of robustness capacities of the farming systems in combination with an enabling institutional environment. Revealed capacities were mainly based on already existing connectedness among farmers and more broadly in value chains. Across cases, the experience of the crisis triggered reflexivity about the operation of the farming systems. Recurring topics were the need for shorter chains, more fairness towards farmers, and less dependence on migrant workers. However, actors in the farming systems and the enabling environment generally focused on the immediate issues and gave little real consideration to long-term implications and challenges. Hence, adaptive or transformative capacities were much less on display than coping capacities. The comparison with pre-Covid findings mostly showed similarities. If challenges, such as shortage of labour, already loomed before, they persisted during the crisis. Furthermore, the eminent role of resilience attributes was confirmed. In cases with high connectedness and diversity we found that these system characteristics contributed significantly to dealing with the crisis. Also the focus on coping capacities was already visible before the crisis. We are not sure yet whether the focus on short-term robustness just reflects the higher visibility and urgency of shocks compared to slow processes that undermine or threaten important system functions, or whether they betray an imbalance in resilience capacities at the expense of adaptability and transformability.

Significance: Our analysis indicates that if transformations are required, e.g. to respond to concerns about transnational value chains and future pandemics from zoonosis, the transformative capacity of many farming systems needs to be actively enhanced through an enabling environment.

1. Introduction

Many farming systems in Europe are struggling with substantial challenges resulting from fundamental changes in their economic, technological, demographic, ecological and social environment (Meuwissen et al., 2020). The resilience of farming systems, i.e. their ability to cope with and respond to shocks and stresses, has therefore become a major concern (BC, 2020). The Covid-19 pandemic and the measures for its containment – e.g. lockdowns, travel restrictions and border closures – were expected to add another shock to farming systems. Using 11 in-depth case studies, this paper investigates the extent to which different farming systems across Europe were affected by the crisis, which resilience strategies they adopted, and which characteristics enabled or constrained their resilience abilities.

This paper contributes to a fast-growing literature on impacts of the Covid-19 pandemic on different parts of agricultural and food systems, e.g. food value chains, marketing channels, trade patterns and food security (e.g. Chang and Meyerhoefer, 2020; Barichello, 2020; Hobbs, 2020; Mahajan and Tomar, 2020; Deaton, 2020). Impacts on different farming sectors, e.g. due to production and demand distortions, have also been discussed (e.g. McEwan et al., 2020; Weersink et al., 2020; Brewin, 2020). Others have reflected on the resilience of food systems at large in the light of Covid-19 (e.g. Orden, 2020; Bené, 2020). However, a systematic assessment how characteristics of farming systems have enabled or constrained their responses to the Covid-19 crisis is missing. By using an elaborate framework (Meuwissen et al., 2019) to assess and compare the resilience of farming systems before and during the pandemic, this paper aims to enhance our understanding (i) how different farming systems were exposed to the crisis, (ii) which resilience capacities were revealed and (iii) how resilience was enabled or constrained by the farming systems’ social and institutional environment.

Section 2 explains the SURE-Farm framework to assess the resilience of farming systems and the special data collection on Covid-19. Results are presented in Section 3, followed by discussion and conclusions in Section 4.

2. Approach

2.1. Resilience of farming systems

Following the social-ecological tradition of resilience thinking (Holling et al., 2002; Walker and Salt, 2006; Folke, 2016), we define the resilience of a farming system as its ability to ensure the provision of its desired functions in the face of often complex and accumulating economic, social, environmental and institutional shocks and stresses, through anticipating, coping and responsive capacities (Meuwissen et al., 2019). The resilience of a farming system is affected by specific system characteristics (resilience attributes (Paas et al., 2021)), and by the enabling or constraining environment, in particular institutional arrangements and resource availability (Termeer et al., 2019; Mathijs and Wauters, 2020). The resilience capacities define the possible range of actions to maintain the desired functions of the farming system, i.e. the provision of private and public goods at desirable levels. The selected courses of action in turn also affect the actors, institutions and resources of the farming system and its enabling environment, constituting a feedback loop.

2.2. Special data collection during early-stage of lockdowns as part of systematic resilience assessment

Resilience is a latent property of a system. The concept denotes a potential which is activated – and can be observed – only when a system is hit by stress or shocks (Meuwissen et al., 2020). It can thus be understood by learning from past trajectories and discussing future scenarios, and from assessing how actual shocks are dealt with (Fig. 1). The first approach was used in a systematic assessment of sustainability and resilience over the course of 2017–2020. This provided insight into the multiple factors contributing to resilience. We used the second approach
when Covid-19 hit European food and agricultural systems. This allowed us to compare the resilience attributes of the system and the resources and institutional support from the enabling environment that were activated to respond to challenges before and during the Covid-19 crisis. The 11 farming systems (Appendix A) have been analysed since 2017 in the SURE-Farm project, which has been funded under the EU research program Horizon 2020 and aims to understand and systematically assess the sustainability and resilience of farming systems.

Qualitative data on the farming systems during the Covid-19 crisis were collected by members of the SURE-Farm consortium in their respective countries in spring 2020, focussing on exposure to restrictions and sensitivity of the farming system, actions taken by farming system actors in response to restrictions, the role of the enabling environment (resource availability and institutional environment), and discussions and reflections triggered by the crisis (Fig. 1). Due to the short time-frame to plan data collection, different methods were used depending on availability and feasibility in each case study. In most case studies, interviews were complemented with a review of media and policy documents (Table 1). Each case study team interpreted the data with a focus on (i) the anticipating, coping and responsive capacities displayed by the actors in the farming systems, (ii) the agility of the actions (i.e. the speed with which actors accepted the situation as a crisis and shifted to crisis mode), (iii) the degree of fragmentation or connectedness across actors and (iv) the display of leadership, i.e. which actors shaped the interpretation of the situation, and provided guidance and coordination (Fig. 1).

The findings on the Covid-19 crisis were then compared to previous insights for each farming system, using selected findings from the systematic resilience assessment. These included findings on resilience capacities, the role of the enabling environment, prevailing challenges, and systems’ performance of resilience attributes such as diversity, profitability and openness (Fig. 1).

3. Results

3.1. Short-term impacts of lockdowns

Exposure and sensitivity differed across farming systems (Table 2). Major exposure and sensitivity were observed in the extensive sheep farming system in Northeast Spain and in the small-scale mixed farming system in Northeast Romania, mainly due to severely interrupted sales to restaurants and peasant markets, respectively. In the small-scale mixed

Table 1

| Farming systems                                      | Interviews (farmers; other FS actors) | Other methods                                      |
|------------------------------------------------------|---------------------------------------|---------------------------------------------------|
| Intensive dairy farming in Flanders, Belgium         | 0; 25                                 | Online farmer survey (n = 191)                     |
| Large-scale arable farming in Northeast Bulgaria     | 2; 3                                  | Media                                             |
| Extensive beef cattle farming in the Massif Central, France | –                                    | Media, interactions with stakeholders and experts through value chain platform |
| Large-scale corporate arable farming with additional livestock activities in the Altmalk in East Germany | 3                                    | –                                                 |
| Small-scale hazelnut production in Lazio, central Italy | 4; 5                                 | Review of media and policy documents              |
| Intensive arable farming in Veenkolonien, the Netherlands | 2; 5                                  | Comments on Facebook of Ukrainian forums devoted to work in Poland |
| Fruit and vegetable farming in the Mazovian region, Poland | 14; 13                                | –                                                 |
| Small-scale mixed farming in Northeast Romania       | 4; 9                                  | Media, review of policy documents                 |
| Extensive sheep grazing in Northeast Spain           | 2; 7                                  | Review of newspaper articles and reports          |
| High-value egg and broiler production in South Sweden | –                                    | Seminar with food system actors, review of newspaper articles, reports and policy documents |
| Arable farming in the East of England, UK            | 3; 9                                  | –                                                 |
Table 2
Overview of exposure and sensitivity, resilience actions, role of the enabling environment and impact in 11 farming systems (FS).

| Exposure and sensitivity | Actions by FS actors | Actions by enabling environment | Impact |
|--------------------------|-----------------------|--------------------------------|--------|
| Dairy farming in Flanders Minor: farmers could continue their production; collection of milk was not interrupted. Negative: reduced opportunities to promote international trade (export is important); some logistical struggles in supply chain; reduced milk prices. Positive: increased sales of fresh milk in supermarkets (as this is the most important supply channel for organic milk products, the organic dairy sector was particularly positively impacted). | Anticipating. Processors: implemented crisis protocols and safety measures before the government imposed them. Coping. Farmers: employed cost-saving strategies; used own buffer capacity to cover financial consequences. Processors: built private stocks and bought storage capacity to avoid waste; mobilised personnel to continue production. National federation of processors: organised dialogue and cooperation between processors to prevent interruptions of milk collection and a collapse of milk processing and packaging activities. Responsive*. Processors: managed to restructure value chains streams. | Coping. Government: declared the food industry as an essential sector, which motivated personnel at the processing plants to keep on working; implemented several subsidies to relief financial consequences, e.g. ‘bridging loans’ (applicable to farmers and intermediaries). | Overall minor impact at farming system level, although there was an uneven distribution, i.e. farmers who produce for the world market were more impacted than those (partly) selling to consumers. Also, processors focussing on restaurants were more impacted than processors delivering to supermarkets. |
| Arable farming in Northeast Bulgaria Minor: production-related operations were only hindered for a short time as lockdown occurred after seeding. Negative: land owners asked for pre-payments due to financial distress. Positive: increased interest into diversification and better planning of financial flows. | | | |
| Beef production in Massif Central Minor: export to Italy continued after initial hesitation. Negative: reduced carcass quality of calves; due to longer period on farms; changed consumption patterns (more frozen and minced meat) led to unbalanced use of the carcasses (less consumption of the most ‘noble’ parts). Positive: less commercial visits to the farm. | Coping. Processors: used veal for production of minced beef. Responsive*. Private companies, cooperatives: organised forms of home delivery, ‘ready-to-work’, and drive-take-aways. | | Minor. |
| Arable farming in the Altmark Minor: lockdown occurred after seeding; previous year’s grain harvest had already been sold. Negative: mental stress (‘what happens to my farm if I fall ill?’); some fertilizers & pesticides were not available for a short period. Positive: public awareness of importance of agriculture (although some politicians argued industrial agriculture was a cause of the pandemic). | Anticipating. Farmers: some purchased seeds, fertilizer, pesticides earlier. Coping. Employees: revealed high level of solidarity (helping each other, working longer hours). | | Minor for short-term period, but possibly medium for long-term period depending on global economic crisis in combination with more severe weather conditions. |
| Hazelnut production in Lazio Minor: lockdown occurred during tillage (not harvest). Negative: some delay in field activities due to interrupted supplies, e.g. of machinery spare parts; changed product demand (less through restaurants, more to retail); collapse of agritourism; cancellation of holy communion feast; parents needed extra time to take care of their children at home. | Coping. Farmers, processors: started processing activities with regard to unsold vegetables. Agritourism: organised training activities for employees to learn anti-Covid-19 measures; rearranged open spaces for hosts. Responsive*. Farmers, processors: improved ICT to enhance order management and e-commerce; organised home delivery of farm products (e.g. fresh vegetables, processed products usually sold at the farm). | Coping. Government: initiated ‘job-in-country’ database for unemployed people (little response); attempted to set up European corridors for foreign labour; provided cash-grant scheme up to 2.5 k€uro per farm with agritourism. Responsive*. Government: reduced red tape costs related to CAP, e.g. by using georeferencing instead of field controls. | Overall minor. Agritourism activities were heavily impacted, but these are only a small part of the overall system. |
| Arable farming in Veenkolonien Minor: lockdown was established before seeding and planting but there was no shortage of materials; main cash crop is starch potato (this market was hardly affected). Negative: some delay in availability of machinery supplies, e.g. spare parts for irrigation equipment; less opportunities for shared learning; some delays in international logistics and payments for processing cooperative. Positive: increased appreciation for countryside. | Coping. Processing cooperative: delayed sustainability goals of growers due to changed priorities; organised multi-functional crisis team. Responsive*. Processing cooperative: led quick transition to online communication with member farmers, including vlogs in demo-fields to update on new developments. | Coping. Government: provided financial support for severely affected farms. Banks: offered opportunity for delayed repayments. | Minor during early stage of lockdown. (There may be a medium impact in the longer term due to lower commodity prices.) |
| Exposure and sensitivity | Actions by FS actors | Actions by enabling environment | Impact |
|--------------------------|----------------------|-------------------------------|--------|
| Fruit & vegetables in Mazovia | **Medium.** Negative: higher prices for fertilizers and pesticides; temporary closing of shops (after re-opening; extra sanitary costs and problems with imports); foreign workers were limited in travelling (when travelling was allowed, farmers had to facilitate quarantine and pay for Covid-19 tests); difficulties in implementing changing Covid-19 regulations. Positive: higher prices for vegetables and fruits (especially in short-term for apples); increased understanding of need for more flexible work permits for foreign workers. | **Anticipating.** Farmers’ organisation: signalled upcoming Labour shortage. Coping. Farmers: ignored to some extent restrictions to sell in crowded places. Retailers: introduced obligatory protective measures to protect buyers and sellers. Foreign workers: intensified communication with intermediaries and among each other (through social media groups created by intermediaries on Facebook and Viber). **Responsive**. Farmers: started online buying of inputs, and online sales; replaced human labour by machines; switched to less labour-intensive vegetables (beans and pumpkins instead of cauliflowers and broccoli). | Minor as increased prices were temporary and farmers managed with available labour. |
| Mixed farming in Northeast Romania | **Major.** Negative: lower sales, e.g. lambs for Easter and fresh early spring vegetable; lower sales in pea Kent markets due to lack of customers’ mobility; lower sales due to abandoned school programs (bread, milk, apples); interrupted deliveries of products to restaurants; lower mobility of commuting workers; reduced off-farm income if family members lost off-farm jobs; collapse of agritourism due to cancellations including those linked to peak periods such as Easter and 1st of May holidays. Positive: increased appreciation for local products. | **Coping.** Agritourism: owners who faced closing of agritourism activities (occasionally) begun with meal deliveries. Processors: reduced buying of milk from farmers due to reduced demand. Peasant markets, retailers: established compulsory protection measures for sellers and customers. Responsive*. Farmers: started online and local direct sales of fresh vegetables, fruit, eggs and dairy. Supermarkets, fast-food: increased home delivery in urban areas. | Overall medium for farmers, although there was an uneven distribution at farming system level, i.e. farmers selling large quantities of products in pea Kent markets and to restaurants were impacted more. Farmers who shifted sales directly to customers and/or internet sales coped better. |
| Sheep grazing in Northeast Spain | **Major.** Negative: interrupted sales to restaurants; sharp drop in prices. Positive: increased public awareness and appreciation of extensive sheep sector. | **Coping.** Farmers: kept animals longer on farm to deal with market oversupply. Slaughterhouses, feedlots: regulated supplies to markets. Responsive*. Farmers: started online sales to consumers. Cooperatives: tried to keep farm-gate prices at reasonable level, e.g. through stimulating national consumption of lamb meat and opening new international markets; developed new products (processed, easy to cook). | Overall medium impact, although there was an uneven distribution, i.e. those farmers who belong to cooperatives (instead of individually dealing with distributors) were better able to ensure sales at fair prices. Also farmers who diversified their activities and distribution channels were better able to cope. |
| Egg & broiler production in South Sweden | **Minor.** Low export orientation. Domestic markets were not severely affected. Negative: some difficulties in fodder imports and access to migrant labour. Positive: less competition from import. | **Coping.** Farmers, processors: hired labour from companies in region that had shortage of work. Responsive*. Farmers, processors: increased use of ICT to find markets and link with consumers. | Overall minor, with few imbalances among actors. |
| Arable farming in the East of England | **Minor.** Lockdown occurred after seeding and planting. Negative: reduced demand for malting barley and potatoes; issues with packaging for flour for retail caused shortages in retail (it took time to redirect bulk supply to retail); slight delay with machinery parts; less activities on diversified farms, e.g. tourism, cafes, weddings. Positive: the image of British farming got a boost as people were looking to buy more local food and appreciated the work done by British farmers to keep the nation fed. They also realised that farmers provide important public goods, such as places for recreation. | **Coping.** Farmers’ organisation: launched a portal to match up supply and demand of potatoes; provided advice and represented farmers to government. Responsive*. Potato growers: shifted from chipping to bulk bags for consumers, where possible. (This was not possible for all growers as stored potatoes treated with GIPC cannot be sold as fresh potatoes if more than 2 applications have been applied. Also, some varieties used for chipping are not suitable for retail.) | Overall minor, although there was an uneven distribution, i.e. those who were entrepreneurial were able to switch quickly to capitalise on the increased retail demand. Also, those who maintained diversity in their markets were better able to adapt. |

*Responsive capacities are subdivided into adaptability (*) and transformability (**). The latter was not observed.

1 Scope of lockdowns slightly varied across EU member states but mainly included lockdowns of schools, (partial) closure of hotels, restaurants and cafes, travel restrictions, and cancellation of large events.
2 The role of the EU is not specified here as they had a role in each FS, e.g. through aids for private storage and implementation of ‘green corridors’ to warrant food security and supply of machinery.
3 Only limited relevance for farmers as they mostly work with family labour and seasonal employees.
In the extensive apple system in Veenkoloniën and the extensive cattle grazing system in the Massif Central important markets (starch potatoes and exports to Italy respectively) were barely affected.

Despite only minor exposure and sensitivity in most farming systems, a wide variety of actions was undertaken across all farming systems (Table 2). Similarities were financial support programs from governments and attempts to set up online-sales channels and home-delivery services. Also, in many farming systems, cooperatives became active. For instance, in the extensive sheep grazing system in Northeast Spain cooperatives kept farm-gate prices at a reasonable level through stimulating national consumption and by developing new markets. In trying to solve shortages of foreign workers, farmers’ associations in the fruit & vegetables system in Mazovia successfully anticipated and started to contact Ukrainian workers directly via Facebook platforms, while the German Farmers’ Association (Deutscher Bauernverband) organised flights for migrant workers, among others from Romania and Bulgaria. The Spanish government ensured availability of shearers from Uruguay. In contrast, in the UK the government tried to mobilise local workers, such as through the ‘Pick for Britain’ and ‘Student Land Army’ initiatives, and in the egg & broiler system in South Sweden unavailability of migrant workers was coped with by hiring furloughed labour from companies in the region.

Impacts were overall minor (Table 2). For instance, in the fruit & vegetables system in Mazovia the speed of arranging availability of Ukrainian workers and the switch to less labour-intensive crops (e.g., pumpkin instead of cauliflower) reduced the system’s medium exposure and sensitivity to a minor overall impact. The early signalling of the forthcoming labour shortage by the farmers’ organisation seemed a pivotal anticipating capacity. Some actions also reduced a system’s exposure and sensitivity. For instance, the agile efforts of Belgian dairy processors to cooperate in order to ensure continuation of milk collection (despite reduced opportunities for valorisation) has been an important factor leading to relatively minor consequences in the Flanders dairy system. A somewhat more nuanced view on impacts came from some farming systems which recognised that impacts were unevenly distributed across actors, depending on membership of a cooperative (e.g., in the extensive sheep grazing system in Northeast Spain) and entrepreneurship (in the arable system in the East of England). Also, despite minor impacts in the short term, some actors in arable systems expressed concerns about long-term consequences on price levels (Veenkoloniën and Northeast Bulgaria).

Most of the long list of actions undertaken by farming system actors and the enabling environment suggest coping capacities. This is especially pronounced for the actions undertaken by the enabling environment; only in the hazelnut system in Lazio and the extensive sheep grazing in Northeast Spain the government was partly responsive through changing physical field inspections to georeferencing and by actively engaging in identifying new export markets respectively. We observed more responsive actions at the level of farming systems; in the large-scale arable system in Northeast Bulgaria and in the extensive sheep grazing system in Northeast Spain even the majority of actions by farming system actors were responsive (adaptive). Anticipation was quite rare and was observed only in the dairy system in Flanders where processors anticipated through crisis protocols, in the arable system in the Altmark where some farmers anticipated and responded by early buying of inputs, and in the fruit & vegetables system in Mazovia in relation to the availability of foreign workers.

Although few actions could be classified as responsive behaviour, the discussions and reflections triggered by the crisis dealt with a range of topics which would require fundamental changes in farming systems or food and agricultural sectors in general. Discussions related among others to calls for more self-sufficiency, shorter value chains, reduced dependence on migrant labour, improved fairness and inclusiveness in value chains, more cooperation among farmers, and more innovations (details are in Appendix B, including whether discussions related to the farming-system level or food and agricultural sectors in general).

Not much variation in agility could be observed; where needed, actions were taken swiftly (Table 3). Only in the hazelnut system in Lazio it was reported that decisions were taken promptly, but that the actual implementation of related actions was slow. Regarding leadership, more differences were observed across farming systems (Table 3). In the three farming systems with the highest exposure and sensitivity, leadership was taken by actors from the enabling environment in the fruit & vegetables system in Mazovia and in the mixed farming system in Northeast Romania, while in the extensive sheep grazing system in Northeast Spain actors from the farming system itself led important actions. In other farming systems, leadership was jointly taken by actors from the farming system and the enabling environment. Connectedness was mostly apparent at the level of processing cooperatives (dairy system in Flanders, sheep grazing system in Northeast Spain) or farmers’ associations (the fruit & vegetables system in Mazovia). Little connectedness was found in the large-scale arable system in Northeast Bulgaria, the extensive beef system in Massif Central, and in the small-scale mixed system in Northeast Romania. In the latter, lack of cooperation along the value chain and between farmers was seen as rooted in the communist history and considered a major problem in developing solutions during the lockdown. In

Table 3
Interpretation of actions during lockdowns: leadership, agility and connectedness.

| Action in System/Region | Was an action taken with agility? | Who took leadership? | Did FS actors show connectedness? |
|-------------------------|---------------------------------|----------------------|----------------------------------|
| Dairy farming in Flanders | Yes | FS2b,e | Yes (FS2b,e) |
| Arable farming in Northeast Bulgaria | Yes (EE4) | FS1b, EE4 | No |
| Beef production in Massif Central | Yes | FS2b,e, EE4 | No |
| Arable farming in the Altmark | Yes | FS1a, EE4 | Negligible |
| Hazelnut production in Lazio | Prompt decisions (EE4) but slow implementation | – | – |
| Arable farming in Veenkoloniën | Yes, but only few actions | – | – |
| Fruit & vegetables in Mazovia | Yes (FS2, EE1c, 4) | EE1c, 4 | Yes (FS1b), no (FS4) |
| Mixed farming in Northeast Romania | Yes | EE4 | No |
| Sheep grazing in Northeast Spain | Yes (FS2b, EE4) | FS2b | Yes (FS4) |
| Egg & broiler production in South Sweden | – | Mix of FS and EE | – |
| Arable farming in the East of England | Yes where needed | – | – |

1 An ‘-’ refers to limited agency, agility etc. because it was not needed.
2 We distinguish between actors from the farming system (FS) and the enabling environment (EE). FS1a, farmers; FS1b, farmers’ associations; FS2b, private processors, FS2c, processing cooperatives; FS2d, association of processors; FS2e, foreign workers, EE1a, farmers’ organisations; EE1b, associations of processors, EE1c, labour organisations, EE1d, private processors, EE2b, cooperative processors, EE3, banks, EE4, national government. EU actions are not specified as they apply for each FS.
3.2. Comparison of pre-Covid-19 findings and Covid-19 crisis

Revealed resilience capacities during the Covid-19 crisis largely coincided with the resilience capacities from the pre-Covid assessment, i.e. also before Covid-19 there was a focus on short-term robustness (coping) as indicated by the frequent ‘b’ in Table 4. However, there were a few exceptions. For instance, in the arable system in Northeast Bulgaria and the arable farming system in the East of England the pre-Covid-19 focus of farming systems was on coping capacities while the Covid-19 situation revealed mainly responsive capacities. With regard to actions taken by the enabling environment, the opposite was true in among others the mixed system in Northeast Romania and the egg & broiler system in South Sweden, i.e. there was more focus on supporting coping capacities during Covid-19 than before.

A comparison of pre-Covid-19 challenges and those observed during lockdowns shows that a number of challenges persisted during the lockdowns (Table 5). (Covid-19) challenges were extracted from exposure and sensitivity (Table 2), observations reported in Table 3 and discussion topics summarised in Appendix B.) For instance, each farming system in which labour shortage was already identified as a top-5 challenge in the pre-Covid-19 assessment (Appendix D) also reported labour issues during the lockdowns (arable system in the Altmark, the fruit & vegetables system in Mazovia, the mixed system in Northeast Romania, and the egg & broiler system in South Sweden). Interestingly, in three farming systems respondents reiterated their worries about climate change, i.e. in the arable system in Northeast Bulgaria, the arable system in Veenkolonië, and the fruit & vegetables system in Mazovia, as they feared that exposure, sensitivity and impact of climate change would be much larger than from Covid-19. The Covid-19 crisis also revealed a number of additional challenges (Table 5). These related to financial distress in the arable system in Northeast Bulgaria and mental stress in the arable system in the Altmark. Actors in three systems also reported problems due to collapse of agritourism activities (the hazelnut system in Lazio, the mixed system in Northeast Romania, and the arable system in the East of England), while such diversified activities were usually assumed to be less vulnerable to external shocks than agricultural production activities. For the mixed system in Northeast Romania and the sheep grazing system in Northeast Spain also the interrupted sales were an additional challenge.

With regard to system characteristics (attributes) that enhance resilience, connectedness stood out (Table 6). Vice versa, lack of connectedness constrained resilience actions. The latter was illustrated by the small-scale mixed system in Northeast Romania in which low connectedness of small farms with value chains hindered small farms to access retail chains when peasant markets closed or were no longer visited by consumers (Table 6, 3rd column). System characteristics however did not explain all patterns of Covid-19 resilience actions (not in table). In two farming systems we observed that pre-Covid-19 connectedness among farmers was high, but this did not play a role during the Covid-19 crisis. In the hazelnut system in Lazio individual farmers took actions, not the cooperative. Also, in the beef system in Massif Central processors took leadership. The opposite was observed in the fruit & vegetable system in Mazovia where pre-Covid-19 connectedness was low, but the Covid-19 crisis revealed that farmers’ and labour organisations were well able to take joint actions to quickly ensure the availability of Ukrainian workers.

4. Discussion and conclusions

In this paper we assessed how and why farming systems in Europe were able to cope with Covid-19. We did so by assessing exposure and sensitivity of farming systems, actions undertaken by farming system

| Table 5 |
|---|
| Persistent and additional challenges during Covid-19. |
| | Pre-Covid-19 challenges which persisted during Covid-19 | Additional challenges |
| Dairy farming in Flanders | Price drops | – |
| Arable farming in Northeast Bulgaria | Climate change | Financial distress |
| Beef production in Massif Central | – | – |
| Arable farming in the Altmark | Lack of skilled labour | Mental stress |
| Hazelnut production in Lazio | Bureaucratic issues causing sluggishness | Collapse of agritourism |
| Arable farming in Veenkolonië | Droughts | – |
| Fruit & vegetables in Mazovia | Overregulation and bureaucracy; low cooperation among farmers; labour shortage; droughts | – |
| Mixed farming in Northeast Romania | Poor integration in agri-food chains; lack of available labour | Interrupted sales; collapse of agritourism |
| Sheep grazing in Northeast Spain | – | Interrupted sales; sharp drop in prices |
| Egg & broiler production in South Sweden | Lack of qualified labour | – |
| Arable farming in the East of England | – | Less activities on diversified farms |

1 Fear that impacts of climate change outweigh those of Covid-19.
In most cases, few anticipatory capacities were observed, even when the impending pandemic became plainly visible through media reports in early 2020. All systems then displayed adequate agility to activate coping capacities. Related actions were led by farming system actors or the enabling environment, or both. Agility was mainly based on already existing connectedness among farmers and more broadly in value chains. Across cases, the experience of the crisis triggered reflexivity about the operation of the farming systems. Recurring topics were the need for shorter value chains, more fairness towards farmers, and less exposure to international trade disruptions. Also, being relatively well socially self-organised enabled hiring of furloughed labour from other companies. High levels of social learning enabled quick change to online sales.

Similar to the results of other studies (Laborde et al., 2020), our case studies found limited impact on the production and delivery of food and other agricultural products. This was due to either little exposure or the agile activation of robustness capacities of the farming systems in combination with an enabling institutional environment. While this constitutes a significant achievement, considerations during the crisis were almost exclusively limited to the productive functions of the system. Impacts on public goods and services barely received attention. Moreover, actors in the farming systems and the enabling environment, or both. Agility was mainly based on already existing connectedness among farmers and more broadly in value chains. Across cases, the experience of the crisis triggered reflexivity about the operation of the farming systems. Recurring topics were the need for shorter value chains, more fairness towards farmers, and less dependence on migrant workers. However, we observed limited adaptive and no transformative responses. This might betray a general orientation towards robustness and attempts to avoid larger changes to the modes of operation.

Similar to the results of other studies (Laborde et al., 2020), our case studies found limited impact on the production and delivery of food and other agricultural products. This was due to either little exposure or the agile activation of robustness capacities of the farming systems in combination with an enabling institutional environment. While this constitutes a significant achievement, considerations during the crisis were almost exclusively limited to the productive functions of the system. Impacts on public goods and services barely received attention. Moreover, actors in the farming systems and the enabling environment generally focused on the immediate issues and gave little consideration to long-term implications and challenges. Hence, adaptive or transformative capacities were much less on display than coping capacities.

The comparison of pre-Covid findings and the Covid-19 crisis mostly showed similarities. For instance, if challenges already loomed before the crisis, they persisted during the crisis, sometimes even to a larger extent. Also, the focus on coping capacities was already visible before the crisis. In addition, the comparison confirmed the eminent role of resilience attributes. For instance, in cases with high connectedness and diversity we found that these system characteristics contributed significantly to the ability to deal with the crisis. However, the findings during the crisis did not entirely reproduce pre-Covid findings, i.e. some cases experienced other challenges, were able to mobilise more responsive capacities than expected, or showed that already existing connectedness did not lead to adequate actions during the crisis. This illustrates the latent, multi-faceted and dynamic nature of resilience.

The data only capture short-term responses to the immediate shock of the first wave of the pandemic and the ensuing restrictions. For instance, we did not assess whether online platforms were sustained. Experiences from later lockdowns during the second and third wave of the Covid-19 pandemic indicate that ‘many had to invent the wheel again’. This resonates with the observation that despite a long list of discussed topics, farming system actors did not use the crisis as a window to trigger more structural change. The only exception in our sample – the prohibition of subcontracting in German slaughterhouses – was forced upon the industry by the Ministry of Labour Affairs, which enabled a change that most observers felt was long due. More than one year into the crisis it becomes clear that the short-term shock evolves into long-term stresses, in particular at the macro-economic level of unemployment, public and private debt and reduced purchasing power.

Sectors that are particularly affected also lose valuable resources, from skilled labour to missing investments and interrupted social and economic network connections. It is plausible that the experience of labour shortages and the importance of digital platforms in developing coping strategies will accelerate trends towards automation and digitalization in the food and agricultural sector as in the general economy.

The findings have important implications for policy making. First, the analysis demonstrates a need to strengthen anticipatory capacities at all levels, in particular the ability to recognise signals of impending threats, whether they are short-term (first wave of Covid-19 pandemic) or long-term (climate change, biodiversity loss). Second, the actors’ reflections in our case studies mostly betrayed a questioning of transnational value chains. Policy makers need to discuss openly whether regional and short value chains are indeed generally more resilient and should therefore become a policy priority. Third, the importance of resilience attributes iterates that system design matters and, thus, that being impacted by a crisis is not ‘just a matter of bad luck’. It needs to be discussed how resilience attributes, such as connectedness in value chains and diversity, can become a more integral part of policy design.

Fourth, the convergence of pre-Covid and crisis findings demonstrates that the systematic resilience assessment of farming systems points at

| System attributes contributing or hindering resilience | High-performing attributes contributing to resilience | Low-performing attributes hindering resilience |
|-----------------------------------------------|--------------------------------------------------|------------------------------------------|
| **Dairy farming in Flanders** | High connectedness among processors ensured continuation of milk collection at farm level, and valorisation. | Low modularity due to asset specificity led to dependence on processors. |
| **Arable farming in Northeast Bulgaria** | – | – |
| **Beef production in Massif Central** | Diversity of buyers including local and export markets was pivotal because export markets remained open. | – |
| **Arable farming in the Altmark** | – | – |
| **Hazelnut production in Lunno** | – | – |
| **Arable farming in Veenkoloniën** | High connectedness across value chain reduced sensitivity due to temporarily delayed sustainability goals. | – |
| **Fruit & vegetables in Mazovia** | Increasing openness to knowledge enabled quick change to less labour intensive crops. | Low connectedness and inclusiveness in value chains impeded small farms to shift markets. |
| **Mixed farming in Northeast Romania** | – | Low exposure to market disturbances caused a lack of alternative sales channels. |
| **Sheep grazing in Northeast Spain** | High connectedness with cooperatives was useful as they managed to keep farm prices at a reasonable level due to investing in consumer campaigns and new markets. | – |
| **Egg & broiler production in South Sweden** | High coupling to national needs, i.e. low export orientation, led to minimal exposure and low sensitivity to international trade disruptions. Also, being relatively well socially self-organised enabled hiring of furloughed labour from other companies. High levels of social learning enabled quick change to online sales. | Low functional and responsive diversity hampered potato farmers who could not switch from bulk to retail. |

1 Pre-Covid-19 performance of attributes was described in Reidsma et al. (2019, 2020).
system vulnerabilities. This knowledge can directly feed into stress tests of food systems. Fifth, the Covid-19 crisis is likely to reinforce concerns about future pandemics from zoonosis and to raise awareness of the interdependence of animal, plant, environmental and human health. From a resilience perspective, such public health issues create system vulnerabilities that might require a transformation, in particular of animal-based farming systems. At the same time, our analysis indicates that the transformative capacity of many farming systems needs to be actively enhanced and stimulated through an enabling environment. This includes (i) the provision of specific resources for a desired transition (e.g., innovative knowledge) and (ii) formal and informal institutional arrangements that provide a clear sense of direction and that enable rather than impede transformations that are necessary to maintain public goods and services.

An important question for future research is whether the focus on short-term robustness just reflects the higher visibility and urgency of shocks compared to slow processes that undermine or threaten important system functions, or whether they betray an imbalance in resilience capacities at the expense of adaptability and transformability. Another task for research is the development of a systematic understanding how short-term crisis interventions to secure the provision of private goods can synergistically support transformations that are needed to address the broad range of challenges to public goods (public health, climate change, biodiversity, farm demographics, etc.).

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**Declaration of Competing Interest**

There is no conflict of interest.

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**Appendix A. A brief description of the farming systems in the SURE-Farm project**

| Description |
|-------------|
| **Dairy farming in Flanders** | Dairy farming is an important agricultural sector in Flanders, the northern part of Belgium. Flemish milk production has increased substantially over the last decade. This is largely because of the structural intensification of the sector, i.e. the number of specialized dairy farms today is similar to 2012 while both the total number of dairy cows and average production efficiencies have increased. Since the announcement of the abolishment of the quota, which was in 2015, scale enlargement has been a dominant trend. But recently also organic dairy farming gained popularity, although it remains a niche. 

**Arable farming in Northeast Bulgaria** | North-East Bulgaria is considered as highly important for crop production. The arable farming capacity in the region results from the natural conditions (fertile soils, varied landscape with semi-mountainous areas, river valleys and lowlands, and a continental type of climate) and is defined by the historical developments and transformations which have taken place during the last decades. Productivity of specialized farms is close to the EU average.

**Beef production in Massif Central** | The Bourbonnais farming system is located in the Charolaïs basin in the centre of France (Massif Central). It is characterized by extensive beef-cattle systems based on grasslands. A large number of weanlings are exported abroad (mainly Italy) where they are fattened. The landscape is characterized by high aesthetic quality (grassland intermingled with a reticulate of hedges).

**Arable farming in the Altmark** | The farming system in the Altmark is dominated by large corporate farms as well as larger family and partnership farms. The farms rely mainly on hired labour and rented land. The fertility of the soils and annual rainfall are rather low. Livestock density is rather low and farms focus mainly on crop production. Despite of the high technical efficiency of the farms their profitability is weak. The region has a rather low population density and poor general infrastructure.

**Hazelnut production in Lazio** | Italy is the world’s second producer of hazelnuts. The farming system, that includes a portion of Viterbo province in Lazio region, produces one third of the Italian production and hosts about 6000 hazelnut farms. Small farms (2-10 ha) dominate (89%), 10% have 10-50 ha and 1% runs more than 50 ha. Hazelnut orchards, due to their profitability, are growing and spreading in less suitable areas where soils, water availability and climate conditions are less favourable. This is generating some opposition from civil society that fears monoculture. However, the quality of the local production is recognised as high (proved by the recognition of PDO “Nocciola Romana”). Most production is supplied through producer organisations to the international confectionery industry, where few players largely dominate.

**Arable farming in Veenkolonien** | The Veenkolonien is located in two Northern provinces of the Netherlands — Drenthe and Groningen. Poor quality of sandy soils makes cultivation of many crops and vegetables impossible, and the farming system hence largely relies on starch potato production in a 1:2-1/3 rotation with sugar beet and wheat.

**Frut & vegetables in Mazovia** | The farming system is located in the Mazovian region in the central-east part of Poland. It is traditionally dominated by horticulture and therefore has a diversified landscape. There are also other types of farms, especially medium-size arable, milk and poultry farms, supplying manure or facilitating crop rotation.

**Mixed farming in Northeast Romania** | The North-East of Romania is dominated by small mixed farms (arable and livestock), generally family run. In terms of size, 98% of the farms in the region have less than 10 ha, 95% less than 5 ha, and 56% less than 1 ha. The main crops grown in the region are cereals (maize and wheat), oilseeds (sunflower), and fodder crops, while the livestock is composed of bovines (mostly dairy cows), poultry, sheep, pigs, bee families and horses for transport purposes. The on-farm consumption is very high (more than 50%) in this region. There are quite few producers’ associations and cooperatives (due to the historical background), and consequently there is poor inclusion in the value chains.

**Sheep grazing in Northeast Spain** | The extensive sheep farming system in Huesca (Aragón), North-eastern Spain has a long history of ovine production. The number of farms and sheep have been more than halved in the last 20 years. Nowadays, the province has around 521,500 sheep heads and 930 farms dedicated to lamb meat production. Farms are mainly medium-size family business (200–1000 sheep) diversified with almond orchards, olive trees, cereal crops and vineyard.

**Egg & broiler production in South Sweden** | Swedish egg and broiler farms produce high-value products, and production is located in the southern part of Sweden, which is recognised for its fertile plain districts and agricultural activities which allow farms to have access to and/or to grow fodder. Swedish egg and broiler farms produce mainly for the domestic market.

**Arable farming in the East of England** | The East of England is considered the “bread basket” of the UK thanks to its extensive flat and fertile land. The region is highly productive in arable crops and contributes more to the UK’s agricultural gross value than any other region. Production includes a wide variety of crops, but cereals (especially wheat and barley) are the most important, accounting for one third of the UK’s entire cereal crop. The farms are large-scale, capital-intensive corporate and family farms.
### Appendix B. Discussions and reflections triggered by the Covid-19 crisis about the farming systems (FS) and the national food & agricultural system (F&A)

| Topics | Details |
|--------|---------|
| Dairy farming in Flanders | - FS. Discussions on need for more vertical communication & coordination.  
- FS. Reflections about risk management, e.g., increased awareness that sector should not depend on government interventions. Also, increased awareness about inflexibility of farmers to adapt production to changing circumstances. This led to debates about among others price contracts. There was also reflection on the limitation of specialising on one market channel, i.e., although highly efficient, it is more safe to spread risk through diversification.  
- F&A. Questions from stakeholders about whether the Belgian dairy sector should focus more on the national market.  
- F&A. Discussions about the opportunity of short supply chains as an alternative business model.  
- F&A. Reflections in society about importance of agriculture and food self-sufficiency. However, the debate was temporary. |
| Arable farming in the Northeast Bulgaria | - FS. Consideration of adaptation and, sometimes, transformation, e.g., towards construction of irrigation systems and other technological innovations, such as more autonomous machineries and transport vehicles, switch to bio-stimulation of soil health, and digitalisation of administrative services.  
- FS. Reflection on further restructuring of land market as crisis is expected to push mal-functioning farms out of business. This will increase trust in the system.  
- FS. Discussions about the need to develop strategies which better target the major national specificities including labour scarcity and climate change.  
- F&A. More societal appreciation for role and importance of agriculture. |
| Beef production in Massif Central | - FS. Press releases from the Ministry of Agriculture highlighting the resilience of the beef value chain in France, but also calling for the need to restructure the chain towards fairer farm-gate prices and a more balanced structure.  
- F&A. Reflections in French society about importance of agriculture and food self-sufficiency. Society also showed feelings of gratitude for the agricultural sector and employees of the food value chain.  
- F&A. Project calls addressing the need to reduce the vulnerability of the French food system.  
- F&A. Reflection in society about food production and self-sufficiency. The debate was however short-lived.  
- F&A. Concerns about the general problem of labour shortage intensified, especially among farmers who rely on labour force from other European countries like Poland (German-Polish border was temporarily closed), Romania and Bulgaria.  
- F&A. Discussions about whether Germans could replace migrant labour in certain sectors such as harvesting asparagus.  
- F&A. Discussions throughout Germany on the bottleneck of slaughterhouse capacities. As a consequence, subcontracting was prohibited in the slaughterhouse business. |
| Arable farming in the Altmark | - FS. Discussions about the vulnerability of agritourism activities, which were usually assumed to be less vulnerable for external shocks compared to agricultural production activities.  
- F&A. Wider reflection at national level on the importance of having more proximity farming, as well as short food chains that better connect agricultural produce with consumers on a local or regional dimension.  
- F&A. Project calling for the need to reduce the vulnerability of the food system.  
- F&A. Reflections in society about food production and self-sufficiency. The debate was however short-lived.  
- F&A. Concerns about the general problem of labour shortage intensified, especially among farmers who rely on labour force from other European countries like Poland (German-Polish border was temporarily closed), Romania and Bulgaria.  
- F&A. Discussions about whether Germans could replace migrant labour in certain sectors such as harvesting asparagus.  
- F&A. Discussions throughout Germany on the bottleneck of slaughterhouse capacities. As a consequence, subcontracting was prohibited in the slaughterhouse business. |
| Hazelnut production in Lazio | - FS. Discussions about the vulnerability of the agri-food system, which were usually assumed to be less vulnerable for external shocks compared to agricultural production activities.  
- FS. & F&A. Wider reflection at national level on the importance of having more proximity farming, as well as short food chains that better connect agricultural produce with consumers on a local or regional dimension.  
- F&A. Project calling for the need to reduce the vulnerability of the food system.  
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- F&A. Discussions throughout Germany on the bottleneck of slaughterhouse capacities. As a consequence, subcontracting was prohibited in the slaughterhouse business. |
| Arable farming in Veenkolonien | - FS. Local innovation centre notified the lack of discussions about fundamental problems.  
- F&A. Scenario thinking about the Post-covid-19 food system in the Netherlands including a scenario on adaptation (‘together in the region’) and transformation (‘rethinking the country side’).  
- F&A. Letter from Ministry of Agriculture to parliament about need to reduce vulnerability of Dutch agro-food system, e.g., through more diversity, cooperation within EU markets, and entrepreneurship, and less dependence on labour migrants.  
- F&A. Discussions in media about the strength of short supply chains and the opportunity to further develop these in order to co-exist next to the longer and more complex chains. |
| Fruit & vegetables in Mazovia | - FS. Discussions about (irrational) hope among fruit and vegetable growers that high prices would prolong and will return in future extreme events.  
- FS. Discussions about importance of better planning, management and coordination among fruit and vegetable farmers, triggered by shortages of pesticides due to stockpiling by some farmers.  
- F&A. Reflections on the need to accelerate IT developments, among others at governmental level (e.g., Paying Agency and National Agricultural Support Center) to ease implementation of CAP, and at farm level to enable more use of IT systems in the field.  
- F&A. Recurring discussions on shortening food chains to enhance stability and food safety.  
- F&A. Reflections on importance of domestic production due to restricted imports in the initial period of the pandemic, and related need to further expand storage systems for vegetables and fruit.  
- F&A. Increased concerns about effects of climate change as impacts are expected to be more severe compared to Covid-19. |
| Mixed farming in Northeast Romania | - FS. & F&A. Ongoing discussions about the vulnerability of Romanian agriculture due to lack of cooperation and poor inclusion of small farms in value chains. The rejection of cooperation is grounded in the Communist history and especially affects small-scale farms, i.e., their production volumes are quite large but due to lack of cooperation produce does not reach supermarkets. Instead, the latter prefer to import milk, dairy products, meat, vegetables and fruit. (The Covid-19 crisis was yet another occasion highlighting some negative consequences of the lack of cooperation.)  
- FS. Discussions about whether farmers’ organisations and cooperatives about the need to improve value chain contracts to avoid price speculation and imbalances in the FS.  
- FS. Reflections by farmers’ organisations about relatively low connectedness among farmers which hindered sectoral agreements to control production in situations of oversupply.  
- F&A. Public awareness about the importance of the agri-food systems and the need to support local/national producers.  
- F&A. Public awareness about the importance of the Swedish food system in general.  
- F&A. Discussions about vulnerable aspects of the Swedish food system in general. This included discussions about how a full lockdown would impact the Swedish food system in general.  
- F&A. Discussions about the need to shorten and re-localise food chains. Part One of the National Food Strategy was rewritten to reflect Covid-19 (and Brexit). So the general discourse is very much reflective on how UK food chains need to be resilient. |
| Sheep grazing in Northeast Spain | - FS. Discussions by farmers’ organisations and cooperatives about the need to improve value chain contracts to avoid price speculation and imbalances in the FS.  
- FS. Reflections by farmers’ organisations about relatively low connectedness among farmers which hindered sectoral agreements to control production in situations of oversupply.  
- F&A. Public awareness about the importance of the agri-food systems and the need to support local/national producers.  
- F&A. Public awareness about the importance of the Swedish food system in general.  
- F&A. Discussions about vulnerable aspects of the Swedish food system in general. This included discussions about how a full lockdown would impact the Swedish food system in general.  
- F&A. Discussions about the need to shorten and re-localise food chains. Part One of the National Food Strategy was rewritten to reflect Covid-19 (and Brexit). So the general discourse is very much reflective on how UK food chains need to be resilient. |
| Egg & broiler production in South Sweden | - FS. Reflections about FS’ weak capacity to adapt, because of its specialized nature across the supply chain and little flexibility due to long-term contracts.  
- F&A. Discussions about whether farmers’ organisations and cooperatives about the need to improve value chain contracts to avoid price speculation and imbalances in the FS.  
- FS. Reflections by farmers’ organisations about relatively low connectedness among farmers which hindered sectoral agreements to control production in situations of oversupply.  
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- F&A. Discussions about the need to shorten and re-localise food chains. Part One of the National Food Strategy was rewritten to reflect Covid-19 (and Brexit). So the general discourse is very much reflective on how UK food chains need to be resilient. |
| Arable farming in the East of England | - FS. Reflections about FS’ weak capacity to adapt, because of its specialized nature across the supply chain and little flexibility due to long-term contracts.  
- F&A. Discussions about whether farmers’ organisations and cooperatives about the need to improve value chain contracts to avoid price speculation and imbalances in the FS.  
- FS. Reflections by farmers’ organisations about relatively low connectedness among farmers which hindered sectoral agreements to control production in situations of oversupply.  
- F&A. Public awareness about the importance of the agri-food systems and the need to support local/national producers.  
- F&A. Public awareness about the importance of the Swedish food system in general.  
- F&A. Discussions about vulnerable aspects of the Swedish food system in general. This included discussions about how a full lockdown would impact the Swedish food system in general.  
- F&A. Discussions about the need to shorten and re-localise food chains. Part One of the National Food Strategy was rewritten to reflect Covid-19 (and Brexit). So the general discourse is very much reflective on how UK food chains need to be resilient. |
Appendix C. Statistical analyses on revealed farm resilience (2007–2013)

| Sample                                      | Composite indicator scores on revealed farm resilience[^1] |
|---------------------------------------------|-----------------------------------------------------------|
|                                             | Farms | Robustness (mean) | Adaptation on arable, crop & perennial farms (mean) | Adaptation on livestock farms (mean) | Adaptation on mixed farms (mean) | Transformation (proportion of transformed farms) |
| NUTS 1/2/3 regions[^2]                      |       |                 |                                                      |                                  |                                  |                                                |
| TF8/TF14 classifier[^3]                     |       |                 |                                                      |                                  |                                  |                                                |
| Dairy farming in Flanders                   | BE2   | 94              | 0.827                                                | 0.258                            | 0.085                            |                                                |
| Arable farming in Northeast Bulgaria        | BG33, BG32 | 104         | 0.756                                                | 0.301                            | 0.067                            |                                                |
| Beef production in Massif Central          | FRK11 | 26              | 0.852                                                | 0.249                            | 0.000                            |                                                |
| Arable farming in the Altmark               | DEE0  | 27              | 0.790                                                |                                  | 0.286                            | 0.222                                          |
| Hazelnut production in Lazio                | ITI4  | 12              | 0.879                                                | 0.428                            |                                  | 0.083                                          |
| Arable farming in Veenkoloni                | NL111, NL113, NL113, NL113 | 40            | 0.878                                                | 0.286                            |                                  | 0.050                                          |
| Fruit & vegetables in Mazovia               | PL81, PL92 | 166          | 0.811                                                | 0.291                            |                                  | 0.193                                          |
| Mixed farming in Romania                    | RO2   | 6               | 0.734                                                |                                  | 0.400                            | 0.500                                          |
| Sheep grazing in Northeast Spain            | ES241 | 33              | 0.781                                                |                                  | 0.367                            | 0.121                                          |
| Egg & broiler production in South Sweden    | SE11, SE12, SE21, SE22, SE23 | 57           | 0.692                                                |                                  | 0.334                            | 0.123                                          |
| Arable farming in the East of England       | UK3H  | 56              | 0.910                                                | 0.279                            |                                  | 0.036                                          |

[^1]: Nomenclature of Territorial Units for Statistics (NUTS) refers to a subdivision of economic territory at 3 different levels. NUTS-regions range from NUTS1 (largest regions), over to NUTS2-regions (regions regional policies apply) to NUTS3 (smallest regions) (European Commission, 2018).

[^2]: TF8 classifiers refer to: 1 = field crops, 2 = horticulture, 3 = wine, 4 = other permanent crops, 5 = milk, 6 = other grazing livestock, 7 = granivores, 8 = mixed (FADN 2018). Selected TF14 classifiers refer to: 20 = specialist horticulture, 36 = specialist orchards - fruits, 48 = specialist sheep and goats, 49 = specialist cattle, 50 = specialist granivores.

[^3]: Following method described by Slijper et al. (2021). Scores can be compared across farming systems (not within a farming system). Top-three in bold, bottom-three in italics. For adaptation this is the top-two and bottom-two (for mixed farms: top-one, bottom-one).

Appendix D. Top-5 challenges identified during systematic resilience assessment.[^1]

| Sample                                      | Challenges                                                                 |
|---------------------------------------------|---------------------------------------------------------------------------|
| Dairy farming in Flanders                   | Volatile milk prices and price drops; low availability and high price of land; extreme adverse weather events; severe and often changing regulations; changing consumer demand to less animal-based food. |
| Arable farming in Northeast Bulgaria        | Constantly changing policies and legal framework; fragmented land ownership and related regulations; low soil fertility; price volatility; climate change; depopulation of rural areas (ageing). |
| Beef production in Massif Central          | Increasing frequency of droughts; low profitability; difficulty to find successors; public distrust of farming practices; low quality of life and work. |
| Arable farming in the Altmark               | Poor soils; increasing effects of droughts; high degree of bureaucracy; very low level of regional infrastructure (marginalized region); lack of skilled labour. |
| Hazelnut production in Lazio                | Rising social conflicts regarding impact on the environment; growing concern about downstream market power; increasing quality standards requested by the confectionary industry; bureaucratic issues causing sluggishness of Pillar 2 payments to farmers; droughts and water scarcity. |
| Arable farming in Veenkoloni                | Constantly changing policies and regulations; extreme weather events; plant diseases and plant parasitic nematodes; low economic margins. |
| Fruit & vegetables in Mazovia               | Overregulation and bureaucracy; lack of long-term vision; low cooperation among farmers due to distrust; lack attractiveness of rural area; labour shortage; price fluctuations; droughts. |
| Mixed farming in Romania                    | Poor integration in agri-food chains; dependence on off-farm income; increased frequency of extreme weather events; lack of available labour due to emigration of young people; constantly changing policies and regulations; social aid system too permissive (disincentive to work). |
| Sheep grazing in Northeast Spain            | Decreasing lamb meat consumption; low attractiveness of sector; low & unequal aid systems; limited access to and availability of pasture lands; lack of social services in rural areas. |
| Egg & broiler production in South Sweden    | Decrease in consumer preferences; lower prices; power imbalances along value chain; lack of qualified labour; obstructing farm succession. |
| Arable farming in the East of England       | Brexit and the uncertainty surrounding the UK’s future market; fluctuating prices (market and input); regulation of plant protection products; labour supply; succession. |

[^1]: Listed in random order (Reidsma et al., 2019).

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