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Research article

The role of diversity and circularity to enhance the resilience of organic pig producers in Europe

C. Pfeifer[a,*], S. Moakes[a], E. Salomon[b], A.G. Kongsted[c]

[a] Department of Socioeconomics, Institute of Organic Agriculture (FiBL), Frick, Switzerland
[b] RISE Research Institutes of Sweden, Uppsala, Sweden
[c] Department of Agroecology – Agricultural Systems and Sustainability, Aarhus University, Denmark

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A B S T R A C T

This paper investigates how pig housing relates to diversity and circularity of farms and how this influences the capacity of European organic pig producers to cope with economic, legislation, labour and climate-related shocks. It identifies resilience strategies of pig producers in Europe by analysing resilience capacity and attributes to different shocks, namely input and output price shocks, disease outbreaks, climate change, legislation change and labour fluctuations. Based on narratives of 18 pig producers, this paper finds three resilience strategies: an efficiency-based strategy, a nutrient substitution strategy and a farm diversification strategy. Non-resiliency is mostly found among the producers with an all-year outdoor production system following the nutrient substitution strategy related to low feed self-sufficiency. The producers follow an efficiency-based strategy when they cannot accumulate reserves sufficient to cope with shocks. Non-resilience among the farm diversification strategy is related to direct marketing that is labour intensive requires the ability to pay decent wages. To increase the resilience of pig producers in Europe, policies should recognise that these different strategies exist and tailor policies differently for different types of producers.

Implications

Organic pig producers follow different strategies to cope with a whole range of shocks, such as economic, legislation, labour and climate-related shocks. These strategies are different to different farming systems with pigs and can be associated with pig housing, diversification and self-sufficiency in feed production. Three strategies are identified: an efficiency-based strategy, a nutrition substitution strategy and a farm diversification strategy. Each of these strategies needs specifically tailored policies to enhance the resilience of pig producers.

Specifications of the provided datasets

Subject	Resilience of pig production systems
Type of data	Table
How data were acquired	State how the data were acquired: farmer's interview State which instruments: data were assessed and visualised in R with dplyr, tidyverse and ggplot2 packages.
Data format	Pretreated data in csv.
Parameters for data collection	Data collectors interviewed farmers in persons in their native language; data were translated to English for interpretation, the data collectors confirmed the interpretation. When data could not be interpreted correctly, farmers were contacted again for clarifications.

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* Corresponding author.
E-mail address: catherine.pfeifer@fibl.org (C. Pfeifer).

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Description of data collection	Data collectors went out with a questionnaire that consisted of four parts. Part one was about the farm and its pig characteristics, part two was about challenges faced by pig farmers. In part 3, farmers were asked to rank their vulnerability to specific shocks, namely input and output price shocks, disease outbreaks, climate change, legislation change and labour fluctuations. The last part asked them how they planned to cope with these shocks. The resulting narratives from part 4 were interpreted based on the Meuwissen et al. (2018) framework of resilient farming systems, identifying resilience capacities, attribute type and attributes.
Data source location	Farmers were interviewed in Austria, Denmark, Italy, Sweden, Switzerland. To ensure the privacy of these farmers, more detailed information about the location will not be disclosed.
Data accessibility	https://zenodo.org/record/5786155.

Introduction

Globalisation of agricultural trade and increased competition in pork production has caused industrialisation, resulting in increased herd sizes and specialisation (Sorensen et al., 2006). These optimised, cost-efficient systems have led to lower animal welfare (Albernaz-Gonçalves et al., 2021) and a higher inherent vulnerability of the pork sector (Millet et al., 2021). This became evident during the recent simultaneous COVID-19 and African Swine Fever outbreaks; producers concurrently faced a drop in pork price, reduced pork demand and limited slaughterhouse capacities (Millet et al., 2021), placing the whole industry under unprecedented pressure (Hobbs, 2021a). These outbreaks have generated new lively discourse about resilience, i.e. the capacity to cope with shocks in value chain and farm system literature. While discourses in the value chain literature reflect on how to make these industrial pig production systems more resilient by increasing their robustness through digitalisation and enhanced slaughter capacities (Hobbs, 2021b and 2021a), the farm system literature suggests that resilience goes beyond robustness: It is about navigating the adaptive cycle, encompassing robustness, adaptability, and transformability (Darnhofer, 2020; Meuwissen et al., 2019) to cope with a broader range of environmental, economic, social and institutional challenges (Darnhofer, 2021a; Meuwissen et al., 2019; Paas et al., 2021). Understanding how to support pig producers to be more resilient from a farming system perspective requires understanding the possible ways to navigate the adaptive cycles, hence looking at farming systems with more adaptable and transformable pig production. These systems are generally less intensive and often found among organic production systems (Sorensen et al., 2006). Organic agriculture, however, is not a guarantee for improved resilience (Milestad and Darnhofer, 2003), and little is known about how these often less intensive organic pig farming systems ensure their resilience, navigate the adaptive cycle, and what can be learned from them to enhance the resilience of the pork sector in Europe.

While organic pig production systems offer the animals an improved possibility to perform natural behaviour (Lund, 2006), they are diverse. Still, they can be described through three dimensions: pig housing, levels of circularity and levels and farm diversification. In Europe, next to the industrial generally fully indoor pig production systems, organic pig production systems are usually classified in three categories of housing: Pigs may be kept entirely outdoors in paddocks, indoors with access to a concrete outdoor run or a combination of both systems depending on the production stages or seasons (Leeb et al., 2019). Whereas purely outdoor systems are generally considered more exposed to disease spread from wildlife (Park et al., 2017), little is known about how pig housing influences the overall capability to cope with a broad range of shocks.

The level of circularity is a promising indicator for resilience (Dumont et al., 2020; Hercher-Pasteur et al., 2021) and resource-use efficiency (Szymczak et al., 2020). Circularity refers to reusing physical materials (Tanzer and Rechberger, 2020). It can be interpreted in the context of pig farming as the extent to which pig producers close cycles, such as nutrient, water, carbon or energy on their farm (Hercher-Pasteur et al., 2021) or in food systems (Van Zanten et al., 2019). The first can be achieved by reconnecting crops to livestock (Billen et al., 2021; Dumont et al., 2013) and generally is achieved through home-grown feed on the farm, also referred to as self-sufficiency or locally sourced feed, while the latter refers to the use of food waste as pig feed (van der Wiel et al., 2020).

There is also growing evidence that more diverse farms are more resilient (Darnhofer, 2010; Dumont et al., 2020; Valencia et al., 2019). Diversification can take place at different levels; at animal levels by keeping different pig breeds, at farm level by combining different livestock species (Dumont et al., 2020) or by combing pig keeping with a range of other agricultural or non-agricultural enterprises, including crops, on-farm processing or tourism (Meraner et al., 2015). Darnhofer (2010) has shown that diversification into niche crops and on-farm rural services such as tourism or on-farm processing can improve resilience, especially for family farms.

Although disparate insights about what makes farming systems resilient are emerging, no studies have focused on farming systems rearing pigs in Europe. Therefore, there is a gap in our understanding of how producers in one of the most volatile agricultural sectors cope with shocks and what role pig housing, circularity, and farm diversification take in ensuring resilience. This study aims to identify resilience strategies of organic pig producers and explore how they combine housing, circularity and farm diversification to cope with a whole range of shocks. The focus on less intensive farms has two advantages. Firstly, it allows an understanding of possible trade-offs and synergies between improved animal welfare and a more "natural life" and resilience. Secondly, it will enable an exploration of a broader range of options to navigate the adaptive cycle for pig producers. It also contributes to a better understanding of principles that allow pig farming systems to cope with upcoming shocks amidst the climate urgency and the related mounting of ecological, social, economic, and political crises.

This paper firstly presents how the framework to assess the resilience of farming systems proposed by Meuwissen et al. (2019) was adapted to pig farming systems. It then presents the case studies and the methodology used to characterise resilience strategies of organic pig producers. The results section shows the characterisation of the resilience profiles found in the case studies, while the discussion highlights the general resilience strategies of pig producers and their implications.

Material and methods

Framework to assess the resilience of pig farming systems

To define resilience strategies for European organic farming systems that rear pigs, referred to subsequently as pig farming systems, this study applies and adapts the concepts described in Meuwissen et al. (2019). This framework suggests defining farming systems (resilience of what?), the function of resilience (resilience for what purpose?) and the challenge (resilience to what?) before exploring resilience capacities and their attributes. The adaptation of this framework to the specificity of the European pig farming system for this study is discussed in the following subsections.

Defining pig farming systems

For this study, the farm is the boundary of the system and the focal scale. It is considered as a unit that produces private rural goods and services, i.e. services for which the farmers receive payments. Next to primary food production, such as crops, feed or livestock, they also encompass activities that require the assets of the farm but are not primary food production, such as on-farm tourism or catering, on-farm processing or retail but also payments directly linked to the provision of ecosystem services through agroecological schemes (Meraner et al., 2015). This definition is broader than the classical definition of farm diversification (Meraner et al., 2015) to encompass both strategies aiming to engage in the cultivation of different crops, or a combination of crop and livestock activities, as well as non-primary food production activities such as tourism or catering.

The farm itself is considered a system that interacts with its biophysical and socio-economic context in which different farm enterprises are combined to produce rural services that include the production of pigs. Pig production can be separated into a pig breeding enterprise (producing weaned piglets) or a pig finishing enterprise (producing finishers) produced in different pig housing types. Within organic pig farming systems, these are generally indoor with a concrete outdoor run, all-year outdoor in temporary infrastructure, or a combination of those two depending on the production stage and season (Leeb et al., 2019). In addition, these pig-related enterprises can be combined with a whole range of other enterprises. For this study, these were categorised into cash cropping (any plant grown to produce food), feed and fodder production (biomass grown for the purpose to feed livestock), other livestock (kept for animal-sourced food production) and finally diversification into the rural goods and services other than primary food production.

While the number of enterprises on a farm reflects the diversity of activities on a farm, certain combinations of farm enterprises enhance the level of circularity on the farm. Notably, the crop-livestock integration improves nutrient cycling (Ryschawy et al., 2017), as a nutrient in the manure is used locally to produce the feed. Therefore, the self-sufficiency of a farm in terms of feed production is an indicator of the level of circularity achieved on the farm. While the nitrogen cycle can also be closed beyond the farm level through specialised farmers collaborating locally by exchanging feed and manure (Martin et al., 2016), externally sourced feed from other regions represents an import of nutrients (Uwizeye et al., 2020). It is generally a source of pollution at the location where livestock is produced (Mueller and Lassaletta, 2020). Yet sometimes, externally sourced feed, hence an import of nitrogen, offers the opportunity to address nutrient deficiencies without relying on artificial fertilisers (Houlton et al., 2019). When the externally sourced feed is food waste, livestock enhances circularity in the food system (Van Zanten et al., 2019). It returns nitrogen that would have been lost otherwise, i.e. leading to pollution at another point of the food system.

Resilience functions of pig farming systems

Given this selected definition of the farm and the focus of this study, the function of resilience is to provide a decent livelihood, both in terms of income and well-being, to the farm household and farm workers currently working in pig farming systems. A pig producer can adapt or transform radically, including adding new enterprises, such as tourism or fattening pigs, and halting non-profitable enterprises. The latter includes the possibility of halting pig production as a whole. In this study, a pig producer who in future stops producing pigs yet still produces other rural goods and services is therefore considered as a resilient farmer, only a pig producer whose entire farm business is ended is considered as non-resilient.

Identifying challenges in pig farming systems

Experts from different European countries involved in the project identified the organic pig sector's most critical challenges, considering the economic, health, environmental, social, and institutional aspects. Economic challenges relate to volatile prices both on the input and the output side. This means that increasing feed prices and decreasing pig and pork meat prices could put farms at risk. Health challenges are related to infectious diseases, such as African swine fever, leading to significant economic losses. Many of these diseases are vector-borne or transmitted through direct contact with wildlife. While exposure to wildlife can be minimised for pigs that are kept solely indoors, pig housing with an outdoor run or entirely on pasture, suitable biosecurity measures can ensure that wildlife is kept distant, for example, through double fencing. Environmental challenges are connected to climate change that is expected to have three significant impacts. Firstly, heat stress days are likely to increase across Europe. This is problematic because pigs are sensitive to heat as they cannot sweat. Therefore, they need management-provided options for cooling through innovations like a shower or having access to shade and wallow. Secondly, the number of days with excess rainfall will increase, leading to more ground saturation and flooded fields. This can be problematic for outdoor pasture-based pig production where better infrastructure and alternative crops (e.g. trees) might be implemented. Finally, highly productive areas of Europe are likely to become more susceptible to extreme weather leading to lower yields for both cash crops and feed and fodder. Social challenges are mainly linked to finding sufficiently motivated and skilled workers for pig production. Institutional challenges are mainly linked to legislative changes, such as the minimum space requirement, tightened organic rules, or stricter environmental policies.

Resilience capacities of pig farming systems

Three resilience capacities can be distinguished: robustness, adaptability, and transformability (Meuwissen et al., 2019). Robustness is the farming system's capacity to withstand stresses and (un)anticipated shocks without adjusting the farm's production. Adaptability is the capacity to change the composition or make changes in the management of their different enterprises, but the structure remains unchanged. For example, a farm that partly produces its feed requirements can relatively easily adjust the ratio of feed that is externally sourced. Finally, transformability is the capacity to significantly alter the internal structure of the farming system by adjusting pig housing or farm enterprises (discontinuing or taking up a farm enterprise) in response to either a severe shock or a chronic stressor that makes business as usual impossible. For example, a producer can give up pig production and replace it with another type of livestock. Finally, the lack of resilience capacity is when a producer discontinues the farms, i.e. all farm enterprises are discontinued.

Resilience attributes of pig farming systems

Resilience attributes are the individual and collective competencies and the enabling (or constraining) environment that enhances resilience capacities. Meuwissen et al. (2019) proposed assessing farming attributes grounded in an adaptive cycle in the context of the five generic principles of resilience, namely diversity, openness, tightness of feedback, modularity, and system reserves.

Diversity does not simply refer to variety but includes three interrelated and distinct components; variety (how many different elements), balance (how many of each element), and disparity (how different the elements are from one another) (Biggs et al., 2012). Examples of these three different components of diversity for pig farmers are the number of different outputs a pig farm is selling (variety), the number of different sale channels for pork (balance), or the number of non-pig-related farm enterprises (disparity).

Openness, which refers to the connectivity between systems (Carpenter et al., 2012), and in the case of farming systems, can be understood as the reliance on resources from outside the farm, for example, the reliance on externally sourced feed or relying on short-term contract staff to address a labour shortage. Tightness of feedback is the response of one part of the system to changes in other parts of the system (Walker and Salt, 2006). In farming systems, this can be seen as how quickly a farmer can adjust, for example, altering the sales price after an increase in feed cost or adapting their infrastructure.

Modularity refers to the fact that a system is made of independent but related subsystems, and when a shock occurs, it remains contained within a subsystem (Carpenter et al., 2012). This definition matches the concept of enterprise in the farming system definition (as described in *Defining pig farming systems*). Each farming enterprise can be considered an independent but related subsystem that allows farmers to reconfigure resources and respond to emerging opportunities.

System reserves provide redundancy and serve as a buffer that allows compensation for the loss or failure of system functions (Biggs et al., 2012). These buffers can be related to economic or natural capital, such as financial savings or soil fertility. Reducing these redundancies can be problematic as these could lead to a system that cannot absorb shocks. For example, when financial reserves are used to cope with a shock, this reserve may not be available for the next shock. Yet, some redundancies are inherent to the farming system in organic agricultural production, and farmers may rely on it without depleting their reserves. For example, organic farmers generally offer more space for each pig, so a legislation change does not affect a system reserve. Similarly, agroecological practices that by definition maintain or build up natural capital, such as soil organic matter nutrient or water storage capacity (Tittonell, 2020), allow a farmer to build up system reserves inherent to the farming system. For example, it allows a farmer to cope better with climate change without depleting resources.

Meuwissen et al. (2019) defined resilience attributes in general terms. Still, the proposed list overlooks that farming systems are social and evolve according to psychological factors such as preferences, aspiration, health, and family composition, all of which play an essential role (Darnhofer, 2021a). For this study, social capital, defined as the ability to rely on networks, trust and goodwill as well as attitude, defined as the psychological factors, were considered as additional and separate resilience attributes, which is in line with Walker and Salt's (2017) list of system resilience attributes.

The case studies

For this study, 18 best practice and innovative pig producers in animal welfare were selected in Austria **(AT01, AT02, AT03, AT04),** Denmark **(DK04, DK05, DK06, DK07),** Italy **(IT01, IT02, IT03, IT04),** Sweden **(SE01, SE03)** and Switzerland **(CH01, CH02, CH03, CH04)**. These cover a broad range of organic pig farming systems across Europe, with different housing types, circularity and diversification levels.

The farms were highly heterogeneous in size and housing-related structures and paddock types. Fig. 1A shows the relation between the farm's size in numbers of pigs expressed in livestock units (**LSU**) and total utilised agricultural area (**UAA**). In addition, it highlights the primary type of structures the pigs are housed within, such as in a permanent or a temporary structure or a combination of the two. Fig. 1B shows the relation between pig stocking intensity (pig livestock units/hectare) and self-sufficiency in feed production on the farm, i.e. the percentage of feed produced on the farm. In addition, the type of outdoor space the pig has access to is shown. These areas can comprise concrete, be situated permanently on pasture or in the forest, or be based on rotational arable land. The latter by construct is always combined with temporary structures.

Most Austrian farms (AT01, AT03, AT04) are medium-sized, with at least one of the pig age groups kept outdoor the whole year round in temporary structures on arable land. AT04 only operates with temporary structures. AT03 and AT04 are solely fattening farms, while AT01 combines breeding and fattening. AT01, AT03 and AT04 have a high level of self-sufficiency and low stocking intensity. On the contrary, AT02 has the largest pig herd in the sample and is a major organic piglet producer; it keeps animals in a permanent building with a concrete outdoor run. It is also the only farm in the sample to feed waste (soy and potato pulp) to pigs.

Fig. 2 presents the different farm enterprises other than pig rearing. AT02, AT03 and AT04 all produce feed, which explains their high self-sufficiency and a cash crop, while AT01 also keeps other livestock and has on-farm diversification activities (direct marketing).

The Danish farms were similar to the Austrian farms as they kept some of the pig age groups outdoor all-year round, on rotational arable land with temporary structures. DK06 operates solely in temporary structures. DK05 and DK07 are solely breeding farms, while DK06 is fattening. DK06 and DK07 both have a relatively low pig stocking density and self-sufficiency, while DK05 is the most intensive pig farm in the sample. DK04 is amongst the largest Danish organic breeding farms and recently added a fattening section due to the loss of a significant customer. It is fairly intensive and among the most self-sufficient farms in the sample. The farms often have other enterprises, with DK05 and DK07 producing their own feed; DK05 also keeps pigs on arable land of a neighbouring farm that produces cash crops. DK06 only produces cash crops, while DK04 produces cash crops and feed.

All of the Italian pig farms keep small or very small herds, with a low pig intensity and all of the farms also allow pigs to roam in the forest. IT04 is the only one that keeps pigs solely in temporary structures. While all farms combine breeding and fattening, IT02 breeds in a traditional way and slaughters all the pigs before the winter, just retaining a few for breeding in the following year. IT02, as well as IT03 and IT04, keep rare breeds. All four farms keep other livestock (beef), have direct marketing, and all except IT02 have on-farm tourism. IT04 obtains its primary income from tourism which also generates customers for direct marketing to their farm as an additional income. In addition to these enterprises, IT01 and IT03 also produce feed and cash crops and therefore have relatively high self-sufficiency.

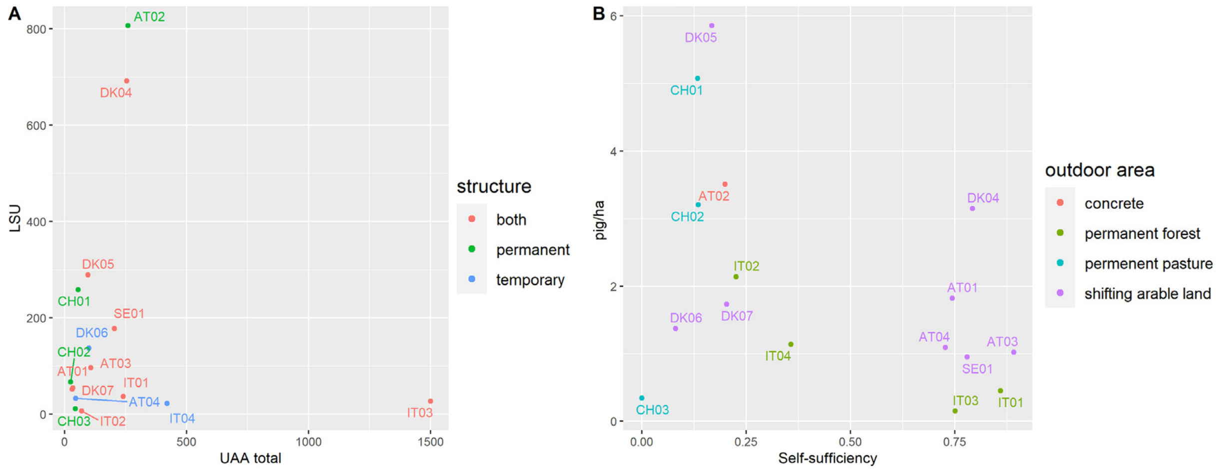

Fig. 1. Participating pig farms (named AT01, AT02, AT03, AT04 (from Austria), DK04, DK05, DK06, DK07 (from Denmark), CH01, CH2, CH03, CH04 (from Switzerland), IT01, IT02, IT03, IT04 (from Italy), SE01, SE03 (from Sweden)) in terms of the number of pigs expressed in livestock unit (LSU), total utilised agricultural area (UAA) and livestock housing structure (A) and the same farms in terms of pig intensity expressed in pig/ha of agricultural area used for the pig enterprise and self-sufficiency in feed production expressed as rate and outdoor area type (B). Note that 2 pig farms, SE03 and CH04, are not presented in both graphs due to missing data.

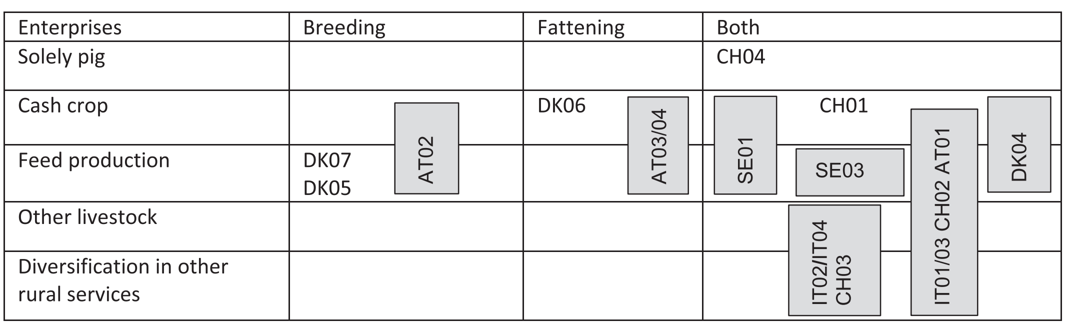

Fig. 2. Selected pig farms (named AT01, AT02, AT03, AT04 (from Austria), DK04, DK05, DK06, DK07 (from Denmark), CH01, CH2, CH03, CH04 (from Switzerland), IT01, IT02, IT03, IT04 (from Italy), SE01, SE03 (from Sweden)) grouped by pig production type and farm enterprises.

The Swedish farms rear pigs on rotational arable land, housed in permanent and temporary structures. Both farms produce feed, while only SE01 also produces cash crops. They combine breeding and fattening and represent typical organic pig farms in Sweden. SE01 has relatively high self-sufficiency; data from SE03 concerning self-sufficiency and intensity are missing.

All Swiss farmers combine breeding and fattening. CH01, CH02 and CH03 keep pigs in permanent structures with access to permanent pasture, while CH04 keeps pigs in temporary structures on rotational arable land. The owner of CH04 does not own any land or farm infrastructure and regularly moves the enterprise to newly rented arable land for around two years at a time. He rears rare breed pigs but generates a significant part of his income off-farm. CH01 is a major organic pig producer in Switzerland that produces cash crops and is the second most intensive farm in the sample with a low level of self-sufficiency. CH02 is a diverse farm with other livestock (sheep), offers to the house for horses, and produces feed and cash crops. Yet the farm's self-sufficiency is low and intensity in the medium range. CH03 is even more diverse, keeps other livestock (beef, dairy, poultry), and has a processing and direct marketing enterprise, but has no arable land, so it is not self-sufficient. However, the farm collaborates with a neighbouring farm with whom they share labour and pig manure for cash crop production, and the pig stocking intensity is among the lowest in the sample.

Data collection and interpretation

To understand farm resilience, farmers were interviewed between the end of 2020 and the beginning of 2021, based on a questionnaire that comprised three sections as described below (the entire questionnaire is provided in the supplementary material).

The first part focused on the farm's challenges in recent years and how they changed—this information recorded as text identified narratives related to self-reported challenges and constraining and enabling factors. The second part focused on six predefined challenges; changing pig prices, changing input prices, an outbreak of infectious diseases, climate change, a labour shortage and legislative changes. To assess their perceived specific resilience to the defined disturbances, farmers were asked how they had prepared for those challenges. This question was very open to capture farmers' narratives related to the perception of their resilience. The narratives were analysed by interpreting the answers into resilience capacities (robust, adaptable, transformable, no resilience) and attributes (diversity, openness, modularity, tightness of feedback, system reserve, social capital and attitude) described in the framework. The third section was a completely open section, where interviewees could reflect on their resilience in general at the end of the interview and add anything they could not say within the relatively strict format along with the selected challenges or anything.

The interpretation of the narratives iteratively took place. Farmers were interviewed in their native languages; data collectors summarised the narratives into English, which a scientist interpreted. This interpretation was then verified with the data collectors, and where ambiguity was found, farmers were contacted a second time to ask for clarification or additional information.

Data analysis

The first step involved coding the qualitative responses to create scores. Resilience capacities were coded as follows: 0 for no resilience capacity, 1 for robust, 2 for adaptable, 3 for transformable. Narratives could contain more than one resilience capacity per challenge; these were all captured separately. To compare farms, resilience capacities were aggregated into a resilience capacity score per farm and challenge, taking the average of the narrative codes. With Ward's method (Ward, 1963), hierarchical clustering is applied to identify different resilience capacity profiles across the different challenges. These profiles are then characterised by farm characteristics with box plots and resilience attributes.

Results

Resilience profiles

Resilience capacity scores derived from the interpretation of the farmers' narratives for each farm are shown in Fig. 3. While most farms were reportedly robust or adaptable, three were reported to be transformative, namely AT04 to disease outbreaks, AT03 to price and DK04 to customer loss. AT03 and AT04 both report an ability to switch to new farm enterprises: AT04 switching from pig to goose, AT03 switching to cash crop production. Due to a customer loss, DK04 recently added a fattening section to its breeding enterprise. Also, some of the farms reported a lack of resilience to specific challenges, namely CH01, SE01, DK05, DK06, DK07, IT03 and IT04. Firstly, DK05, DK07 and IT04 all reported a lack of resilience to a disease outbreak; these are also the farms that operate mainly outdoor structures, with little ability to house pigs safely from interacting with wildlife. Similarly, DK06 operates fully outdoor with temporary structures reported a lack of resilience if affected by a disease outbreak, but his outdoor system would bring forth animals robust to diseases. Italian farms not relying on family labour (IT03 and IT04) reported a lack of resilience capacity to the labour challenge as they cannot pay decent wages. CH01 reported the inability to cope with an increasing input price. It justified this answer with the necessity to use all his savings due to the recent increase in feed cost in Switzerland to be able to continue the business. SE01 reported that a further decrease in pork prices would disrespect the farmer's work. The lack of appreciation of society for producing pigs with high animal welfare standards would demotivate her to the point of stopping production.

Three clusters were found: Cluster 1 (CH01, CH03, CH04, SE01, SE03, AT01, AT02) are farms that are mainly robust and adaptable; cluster 2 (IT01, IT02, IT03, AT03, AT04, DK04, CH02) are farms that are adaptable and transformable, and cluster 3 (DK05, DK06, DK07, IT04) are generally farms that have reported not being resilient to disease outbreaks or legislation. Fig. 4 shows the characteristics of farms in the different clusters. Only self-sufficiency and the number of non-farm enterprises are significantly different in Cluster 2 from Cluster 3. Yet, the median farms in Cluster 1 have a higher pig density, have more pigs, and less land than those in other clusters. Also, the self-sufficiency is relatively low and tends to have permanent structures. Cluster 2 at the median tends to have high self-sufficiency in feed, low pig stocking density and many different non-pig-related enterprises. Finally, Cluster 3 groups most of the farms that tend to produce outdoor the whole year round (no permanent structures only).

Resilience attributes

The ratio between the number of times a given resilience attribute was mentioned to identify patterns among resilience attributes. The number of farms in the cluster was computed for each challenge (Fig. 5). In terms of climate change, mostly Cluster 2, but also producers in other clusters rely on inherent natural capital to cope with climate change. Most farmers reported already utilising trees for shade (IT01, IT02, IT03, IT04), having a sturdy, resistant breed (IT01), already having wallows (AT02, AT04), are working with nature (AT01) and, more precisely, creating microclimates (CH03) and investing in good soil health for water retention (SE03). In Cluster 1, some farms also report having good on-farm

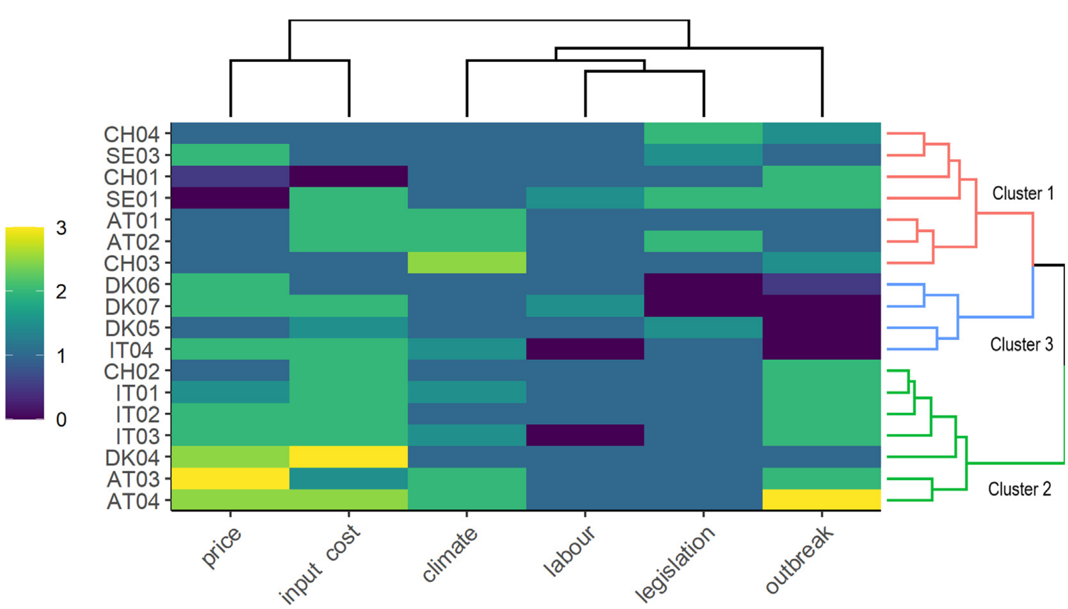

Fig. 3. Perceived resilience capacity scores of each pig farm (named AT01, AT02, AT03, AT04 (from Austria), DK04, DK05, DK06, DK07 (from Denmark), CH01, CH2, CH03, CH04 (from Switzerland), IT01, IT02, IT03, IT04 (from Italy), SE01, SE03 (from Sweden)) and clustering following the ward method.

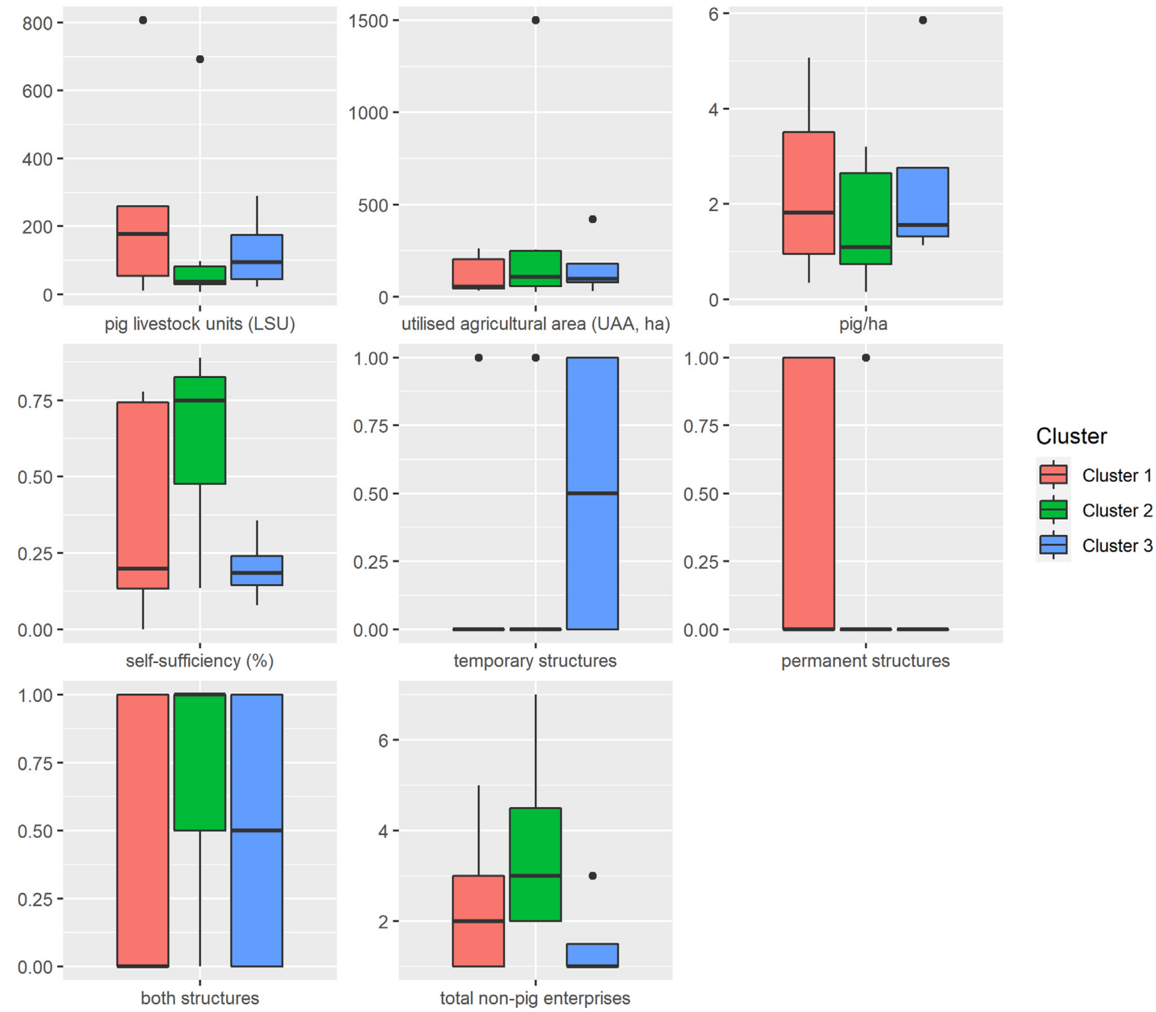

Fig. 4. Comparison of pig farm characteristics between three different resilience clusters. The box represents the 25th to the 75th percentile distribution of the data of the specific group, while the line in the box represents the median value of each group.

infrastructure or technology, allowing them to cope with increased temperature (SE03, CH02, and CH04) or having a mobile production system (DK06). In terms of input costs, Cluster 2 producers often rely on modularity; this is the ability to adjust farm activities between different existing enterprises. These farms follow a similar strategy for output price and outbreak-related shocks. The most-reported coping strategies based on modularity were enhancing the production of own feed (IT01, IT03, AT01, AT02, CH02) or other livestock (AT03, AT04, IT02, IT04) or cash crops (AT04). Cluster 3 mainly reported tightness of pricing feedback because most farms in this cluster are located in Denmark, where the sector is organised through a farmer-owned supply chain. Each Danish farmer is reported to be resilient to input cost shock as they own the whole value chain and would, to a certain extent, be able to adjust output prices. Cluster 1 reported relying on social capital, such as having good customer relations (SE03), or an own brand with good social media marketing (CH04), relying on the sectoral organisation to engage in politics to increase the subsidies to pig farmers (CH01).

In terms of output price, Cluster 2 relies mainly on modularity, similarly to the input cost challenges, but also with a high tightness of feedback, driven by those farmers that have direct marketing (IT01, IT02, IT03, IT04, CH03, CH04, AT01) both found in Cluster 1 and Cluster 2. A relatively common answer referred to diversity, having diverse marketing channels (CH03, IT01) or producing a niche product (SE03, AT01) that would not be affected by a price shock. Furthermore, IT01 also reported producing various products and would produce more conservable products such as salami when the price drops. Also, AT02, one of the significant organic piglet producers in the country reported having a monopoly position through which they do not receive price shocks for piglets. All farms that reported no resilience attribute in terms of price are in Cluster 1 (SE01, CH01).

In terms of labour, most farms are family farms, relying on their own human capital (IT01, IT02, IT03, IT04, CH03, CH04, AT02, AT03, AT04, DK05, DK07). This is a little lower for Cluster 1 that relies more on social capital, be it on networks of volunteers (CH03, DK06, IT01, IT02), training young people (DK04, DK05, DK07, SE01, CH01), attracting workers to work for interesting farms with good animal welfare (CH01, DK04) also promoted through social media (SE01). DK04 reported creating a young pig farmer's network, making the farm popular for young people to join, ensuring that the farm never misses workers. Also, AT02 and CH02 reported relying heavily on mechanisation hence not needing a skilled labour force. SE03 also reported relying on part-time relief workers provided through the staffing agency managed by the extension service. While this scheme is under critique in Sweden and threatened with dissolution, the farmers reported that it plays a significant role in her resilience to a labour shock.

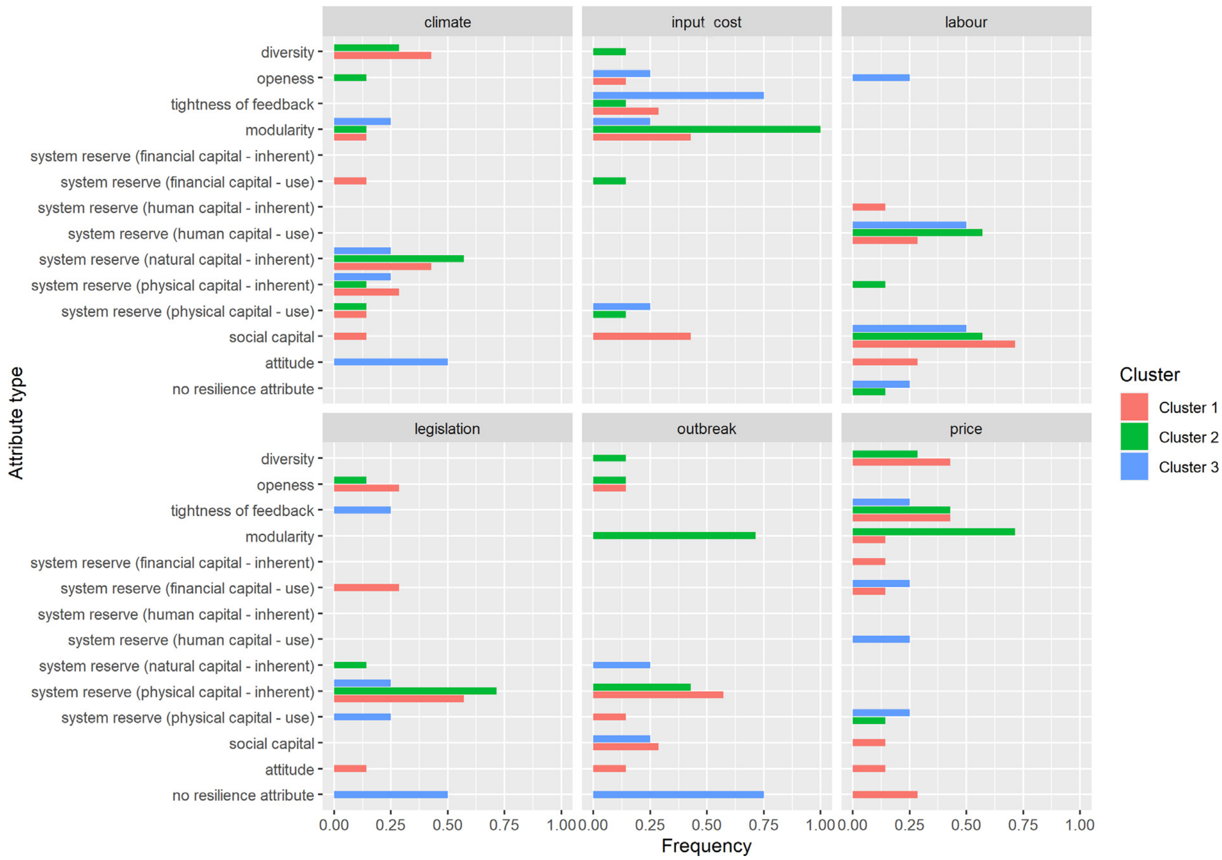

Fig. 5. Resilience attributes in terms of the ratio between the number of times mentioned and number of pig farms in the cluster, per challenge.

In terms of legislation, most farms responded to providing more space to their animals than required by law; hence, they have inherent physical capital reserves. Only outdoor farmers in Cluster 3 reported that legislation change might entail a prohibition of outdoor production with a temporary structure linked to a possible outbreak of African Swine Fever, which explains the no resilience attribute in this cluster.

Regarding a disease outbreak, the outdoor farms in Cluster 3 report having no resilience attribute, while Cluster 2 relies on their modularity, switching the emphasis to other enterprises on their farms. Cluster 1 and some farms in Cluster 2 report having sufficiently good infrastructure, such as indoor production (AT02, AT03, IT03, CH01, CH02) or double fencing (IT02, AT01, CH03) that protects them from an outbreak. Moving to indoor production can imply a change in the meat's brand (AT03). Also, CH04 reported relying on a neighbourhood early warning system.

Authors' point of view

Other resilience patterns

Some resilience patterns did not cluster in this analysis and can be found in any three clusters. Farmers with direct marketing (IT01, IT02, IT03, IT04, AT01, CH03, CH04) are robust to price and cost. They can adjust sale prices due to a shock, i.e. relying on tightness of feedback to enhance the resilience of these farms. While direct marketing ensures less market price change exposure and enables robustness, it often comes with lower labour productivity (Hochuli et al., 2021; Mundler and Jean-Gagnon, 2020) and does not bring higher income compared to farms without direct marketing (Hochuli et al., 2021). This also explains why these farms, when not run as a family, have problems offering sufficient wages and report no resilience capacity to labour shocks (IT03). Most farms rely on family labour to remain robust to labour-related shock, relying on distributing work among different family members or neighbourhood/volunteer networks, hence relying on social capital. Few, however, have reported increasing their own labour (DK05, DK07), which was perceived as a negative on their well-being.

Attitude, be it the entrepreneurial or innovator spirit or a strong belief in organic principles as the only way forward, enhances the robustness of the farms. DK04 reported that their belief in organic systems had given them the courage to transform the farm and add a new finishing section due to a significant customer loss. DK05 reported that they are used to a harsh climate and are robust to climate change. Innovation spirit was mentioned by AT02, the only indoor producer in the sample, who would invest in new infrastructure if concrete runs do not provide sufficient animal welfare for organic certification. SE03 stated that she would always find a solution whatever happens with pork prices or with the labour market for skilled labour. This confirms the conclusion of Darnhofer (2021a) that agricultural production is shaped by social and psychological factors, including individual preferences and aspirations.

Resilience strategies

From these clusters, three resilience strategies can be interpreted from the farmers' narratives, namely an efficiency-based strategy (Cluster 1), a farm diversification strategy (Cluster 2) and a nutrient substitution-based strategy (Cluster 3).

Efficiency based strategy

Cluster 1 tended to group farms with higher pig density in permanent structures and relatively lower self-sufficiency. These pig farms operate focusing on efficiency and productivity gains, following a pattern of industrial, agricultural production and an efficiency-based strategy. SE03 reported working following the lean production principle focusing on more specialisation, formalisation and standardisation (Melin and Barth, 2018). These farms have often invested in good infrastructure (SE03, CH04, AT01), associated with high fixed costs. Therefore, they are also financially locked in (Kuokkanen et al., 2017), making it challenging to transform the farm (Paas et al., 2021). Hence, pork price and feed cost are the more critical challenges these farms face. They tend to ensure resilience through robustness, which is often insured through financial (CH01, CH03, AT02) or physical (SE03) capitals or insurance schemes, or they report having no resilience capacities to a pork price decline (SE01, CH01) or relying on sectoral mobilisation in the value chain to avoid a price reduction (CH01). These farms have a relatively high share of financial capital investments in infrastructure that cannot be reinvested without making a substantial loss, known as sunk costs in economics (Paas et al., 2021). These sunk costs can create path-dependency (Chavas, 1994) and lock-in of farms (Balmann et al., 2006) that cannot invest before they have built up new system reserves, mainly capital reserves. These farms are confronted with higher adjustment costs and adapt and transform slower than farms with lower investment levels (Aderajew et al., 2019). These farms need to ensure that financial capital is available through savings or insurance during a shock. Currently, in Europe, these insurances focus on accident and non-epidemic disease (Bielza Diaz-Caneja et al., 2009). With increasing climate change and related increased volatility across all sectors, there is a need to explore alternative financial products such as index-based insurances or risk contingent credit for the pork sector (Mechler et al., 2010).

Farm diversification strategy

Farms in Cluster 2 tend to be very diverse, and pig production is just one part of their business; most of them have a least three other enterprises than pigs (breeding or fattening) (IT01, IT03, DK04, CH02). These farms follow a farm diversification strategy. In terms of infrastructure, they tend to have both permanent and temporary infrastructure (IT01, IT02, IT03, AT03, DK04, CH02), which give them more flexibility to cope with diseases. Resilience in this cluster is driven by modularity, the ability to adjust and transform the farm relatively quickly to changing conditions.

A critical narrative to transformation was the reporting that should pig production not be profitable enough, AT04 would switch to geese production, and AT03 would focus on crop production instead of pigs. Their feed production combined with crop production allows them to adapt the farm to market prices and cost (IT01, IT03, CH02). This is in line with agroecological research, showing that crop-livestock integration improves self-sufficiency and resilience of the farm and is a win–win strategy that can comprise good economic and environmental performances (Bonaudo et al., 2014). These more diverse farms are generally less efficient than the efficiency-based group. Still, they tend to close nutrient and carbon cycle better (Szymczak et al., 2020) and are better suited to adopt agroecological principles (Phocas et al., 2016) and enhance circular economy (Noya et al., 2017).

These farms are also those that keep traditional and rare breeds. In support of this strategy, new pig breeding strategies, driven by public policies aimed at local breeds, improved information concerning the genetic resources, breeding tools available for agroecological management would be needed (Phocas et al., 2016). Simultaneously, more attention should be given to the economic viability of this livestock that is often low (van der Ploeg et al., 2019). However, there is growing evidence that agroecological farming can generate farm incomes that exceed conventional and industrial farms (van der Ploeg et al., 2019).

Nutrient substitution-based strategy

Cluster 3 brings together farms that focus mainly on outdoor production. If available, the permanent structure plays a marginal role in their production systems as most of the production is outdoor, generally part of the rotational arable land. The outdoor setup makes these farms prone to animal disease outbreaks. It is increasingly under pressure to increase biosecurity measures or abandon the system (Jurado et al., 2018), explaining their low resilience capacity regarding an outbreak or legislation.

Unexpectedly, almost all farmers in this cluster have reported relying on tightness of feedback to cope with an input price change, relying on the fact that the price of pork will adjust to the cost of feed relatively quickly. This answer is driven by the fact that most farmers in the cluster are located in Denmark, where the value chain is owned by the farmers themselves (Hobbs and Jill, 2001), and is the result of long-standing development in cooperatives (Karantininis, 2007) that has led to a horizontal development of the value chain, that gives power to farmers up-until today (Strandskov, 2019).

These farms mainly rely on external feed compared to the farms with a diversification strategy, so not close the nutrient cycle on their farms. This approach is widespread among organic farms that dispense with artificial fertiliser and therefore tend to rely on their own farm manure (Løes et al., 2017; Reimer et al., 2020), including Danish pig farms (Nielsen and Kristensen, 2005). As a result, these organic farms have a lower local ecological pressure from manure compared to conventional intensive pig production, which relies on the externally sourced feed and which manure is a waste that needs to be transported away, potentially exporting pollution to other location (Uwizeye et al., 2020). Nonetheless, there is evidence of nutrient leaching in organic outdoor systems (Manevski et al., 2019). To reduce the risk of leaching, innovative practices such as short but intensive rotational grazing (Juul et al., 2021) with mobile housing systems to move the pig quickly and efficiently on a daily (as implemented by DK06) or monthly (as implemented by DK07) or agroforestry system trees (Jakobsen et al., 2019) are needed.

Likely, these nutrient substitution strategies might increasingly become under pressure. With the European green deal objective of 25% organic production (Moschitz et al., 2021), reliance on manure as fertiliser is likely to increase. At the same time, organic production guidelines increasingly limit feed sourced from outside the region where the animal is located. This will limit the number of pig farms following a nutrient substitution strategy. Relying more on agri-food waste as feed-in, these low self-sufficiency organic pig systems could enhance the circularity in the food system (Van Zanten et al., 2019) while bringing nutrients back to organic farming systems that would be nutrient deficient without livestock. Therefore, organic guidelines should exclude agro-food waste from the principle of feed grown in the region where the animal is located and incentivise the organic pig farming systems with low self-sufficiency to rely more on agri-food waste as feed.

Limitation of the approach

The proposed framework assesses the resilience of objectively defined criteria derived from Meuwissen's framework but subjectively assessed based on farmers' own perception of their resilience. This subjective assessment can lead to biases. For instance, Danish farmers perceive themselves as non-resilient to disease outbreaks, despite the majority having double fencing due to their outdoor production. In contrast, others perceive themselves as resilient because they have double fencing (IT02, AT01, CH03). This different perception, particularly about the capacity to cope with infectious diseases, can be explained by the proximity to African Swine Fever outbreaks before the survey, hence 2019, when the disease hotspot was in the Baltic states and northern Poland (Guberti et al., 2019) and differences between countries in the socio-economic consequences of pig-related disease outbreaks (Niemi, 2020). The strength of this approach is that it factors in people's evaluation of their own ability to deal with risk (Jones, 2019) and allows us to account for attitudes. Yet, the objective criteria definition hampers the capacity to capture any time scale effects and the narrative flow. As a result, the approach does not recognise that farmers' decisions are path-dependent, i.e. dependent on previous decisions influenced by many dimensions. Therefore, it is difficult to apprehend which phase of the farm's adaptation cycle and understand the dynamics driving the transition from one phase to the other. To capture this, approaches that subjectively define resilience, i.e. based on the peoples' judgement of what resilience means, would be needed (Darnhofer, 2021b). Instead, this study identifies resilience strategies how farmers usually navigate the adaptive cycle but cannot predict unexpected trajectories or explain dynamics that would allow a farmer to switch from one to another strategy. The latter would be essential to understand how to incentivise farmers to move from one to another pig farming system in view of a transition towards a more sustainable and circular food system.

Conclusion

This study assessed narratives of 18 organic pig farmers in Europe around their capacity to cope with differing system perturbations. These were identified as a reduction in the price of pork, an increase in input prices, climate change impacts, an outbreak of African swine fever, and a labour shortage. Three different strategies were identified through which these farms try to ensure resilience, but these strategies may also lead to possible non-resilience:

1. An efficiency-based strategy tends to be followed by pig farmers who invest heavily in good infrastructure and rely on financial system reserves to cope with shocks. This investment into the infrastructure can create a lock-in situation, as farmers cannot transform their farms until they build up the system reserve. These farms become non-resilient when there are insufficient system reserves available.
2. A nutrient substitution strategy, where pigs are kept outdoor on arable land and fed on external feeds, importing external nutrients into the organic farming system. None resilience in this strategy comes from legislation changes. Either through the prohibition of outdoor production to control outbreaks of infectious diseases at the wildlife livestock interface, such as the African swine fever or increased restrictions on nutrient and feed imports in future organic legislation.
3. A farm diversification strategy to have several farm enterprises, for which modularity allows them to navigate the adaptive cycle more easily. Yet this approach requires greater skills and maybe labour intensive. Therefore, non-resilience in this group is generally driven by the inability to pay sufficient wages and, therefore, the incapacity to cope with labour shocks when relying on direct marketing.

Results have also shown that attitude, whether in terms of a strong belief in organic principles or an innovator spirit, and social capital plays a vital role in the resilience of pig producers. Due to the diversity of strategies and personal attitudes, policies need to be tailored differently for different producers.

Ethics approval

All participants provided written informed consent before enrolment in the study.

Author ORCIDs

Catherine Pfeifer: https://orcid.org/0000-0001-9738-8758
Simon Moakes: https://orcid.org/0000-0002-0519-2254
Eva Salomon: https://orcid.org/0000-0002-1260-4835
Anne Grete Kongsted: https://orcid.org/0000-0001-7040-7445

Author contributions

C.P and S.M. developed the main conceptual ideas. S.M developed the questionnaire with the support of E.S, and A.G. K. C.P. interpreted the narratives in collaboration with the data collectors and processed the data. S.M, E.S and A.G. K. supported C. P. with interpreting the results. C.P. took the lead in writing the manuscript. All authors provided critical feedback.

Declaration of 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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