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Managing extreme weather and climate change in UK agriculture: Impacts, attitudes and action among farmers and stakeholders

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ABSTRACT

Although the need for agriculture to adapt to climate change is well established, there is relatively little research within a UK context that explores how the risks associated with climate change are perceived at the farm level, nor how farmers are adapting their businesses to improve resilience in the context of climate change. Based on 31 in-depth, qualitative interviews (15 with farmers and 16 with stakeholders including advisors, consultants and industry representatives) this paper begins to address this gap by exploring experiences, attitudes and responses to extreme weather and climate change. The results point to a mixed picture of resilience to climate risks. All interviewees had experienced or witnessed negative impacts from extreme weather events in recent years but concern was expressed that too few farm businesses are taking sufficient action to increase their business resilience to extreme weather and climate change. Many farmers interviewed for this research did not perceive adaptation to be a priority and viewed the risks as either too uncertain and/or too long-term to warrant any significant investment of time or money at present when many are preoccupied with short-term profitability and business survival. We identified a range of issues and barriers that are constraining improved resilience across the industry, including some lack of awareness about the type and cost-effectiveness of potential adaptation options. Nevertheless, we also found evidence of positive actions being taken by many, whether in direct response to climate change/extreme weather or as a result of other drivers such as soil health, policy and legislation, cost reduction, productivity and changing consumer demands. Our findings reveal a number of actions that can help enable adaption at the farm level including improved industry collaboration, farmer-to-farmer learning, and the need for tools and support that take into account the specificities of different farming systems and that can be easily tailored or interpreted to help farmers understand what climate change means for their particular farm and, crucially, what they can do to increase their resilience to both extreme weather and longer term climate risks.

1. Introduction

The need for the agricultural sector to manage the risks associated with climate change is well established, but understanding how these risks are perceived and responded to at the farm level – i.e. by those directly involved producing our food – has been a relatively neglected issue in recent research, certainly within the UK context. This paper begins to address this gap by presenting findings from

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qualitative research exploring farmers' and other agricultural stakeholders' experiences, attitudes and responses to extreme weather and climate change in the UK.

The urgency of adapting agri-food systems to new and changing climatic conditions cannot be overstated, particularly in the context of food security and the related challenges of a growing global population, political turbulence, and shocks such as the Covid-19 pandemic. The range and extent of extreme weather and climate change impacts on agricultural production, both globally and in the UK, are increasingly well recognised (EEA, 2019; Morison and Matthews, 2016; Benton et al., 2012; POST, 2019), having long been discussed within the scientific community (e.g. University of Warwick et al., 2008; Lorenzoni et al., 2001; Knox et al., 2010). In the UK, associated impacts are not all negative but include opportunities for (amongst other things) the introduction of certain crops that were previously only marginally viable, if at all (Morison and Matthews, 2016), as well as increased grassland productivity in some regions (Ritchie et al., 2019). Nevertheless, significant threats remain and the increasing frequency of extreme weather events is already affecting food production across the country. The hot, dry summer of 2018, for instance, contributed to 30,000 additional cow slaughterings, 6% lower wheat yields and 10% lower spring barley yields (compared with the 5 year average) (NFU, 2018). Meanwhile the wet autumn of 2019 proved extremely challenging across the sector, with operational delays resulting in (for example) an anticipated 13% fall in winter wheat planting (AHDB, 2019).

In the UK, the need for adaptation across society is enshrined in policy through the Climate Change Act 2008, which requires a five-yearly Climate Change Risk Assessment, and the National Adaptation Programme, which sets out the government's strategy for responding to the risks and opportunities identified. The most recent evidence report for the Second CCRA was conducted in 2016 (CCC, 2017), and the Second National Adaptation Programme published in 2018 (Defra, 2018b). Agriculture is identified within this programme as having "a vital role to play in managing the UK's land and landscape" (p. 27) and as contributing to wider societal adaptation through supporting biodiversity, flood risk mitigation and soil management. The document sets out pathways for government support for adaptation within the sector (primarily through the government's 25 Year Environment Plan (Defra, 2018a) and forthcoming Environmental Land Management (E.L.M) programme), but adaptation is primarily framed as being the responsibility of farmers with "much of the planning rightly fall[ing] to individual farm businesses" (p27-28). With this is mind, as the third CCRA approaches in 2021 it is essential that we seek to understand not just the impacts on agriculture from climate change but also the perceptions of, and adaptive responses to, these impacts among those on the frontline – i.e. farmers. Ultimately, the severity of impacts – and success of climate policies – is dependent not only on the extent of climatic changes, but also on the measures that are put in place to manage them at the farm level. These, in turn, are dependent on farmers' awareness, knowledge and beliefs about how they will be - or are already being - affected (Eitzinger et al., 2018; Peltonen-Sainio et al., 2020; Hall and Wreford, 2012).

Aside from government policy, agricultural trade bodies such as the National Farmers Union (NFU), Agriculture and Horticulture Development Board (AHDB) and Country Land and Business Association (CLA) also advocate the benefits of adapting to extreme weather to their members (e.g. AHDB, 2020; NFU, 2020; CLA, 2020). Nevertheless, surprisingly little recent research has explored how farmers and others stakeholders perceive climate risks and the need to adapt their business practices in the UK context (a point also noted by Osborne and Evans, 2019; exceptions include Tate et al., 2010; Geoghegan and Leyson, 2012), though studies have addressed the topic elsewhere, for instance in the US (Arbuckle et al., 2015; Houser et al., 2019; Saylor Mase et al., 2017), Australia (Robinson et al., 2018) and various European countries (Käyhkö, 2019; Nguyen et al., 2019, 2016; Peltonen-Sainio et al., 2020), as well as across the developing world (e.g. Asrat and Simane, 2018; Matsalabi Ado et al., 2019; Singh, 2020).

This paper investigates these issues through presenting findings from qualitative interviews with a range of farmers and agricultural stakeholders in the UK. We begin by providing an overview of current understanding around farmer perceptions of climate change and levels of adaptation at the farm level, before introducing the research project and empirical evidence. We then discuss the results of our study, focusing on the details emerging from participants' accounts in relation to i) perceptions of the risks and opportunities associated with climate change; ii) how UK agriculture has already been affected by extreme weather; and iii) their responses to these impacts, particularly the challenges they face in incorporating adaptation into their everyday farm practices and long-term business strategies. Implications for policy and industry are also commented on as part of these discussions. We end by summarising the key conclusions from our research.

2. Background

2.1. Public and farmer perceptions of climate change

Research among the general population has provided a number of insights into how the UK public perceive climate change. For example, there appears to be widespread recognition that weather patterns are changing, and a common tendency for conflation both between climate change and other environmental issues (Taylor et al., 2014) and between the concepts of mitigation and adaptation (Harcourt et al., 2019). Research has also established a relationship between recent experiences of extreme weather and people's perception of climate-related risks, highlighting the influence of what is known as the *availability heuristic* (Taylor et al., 2019) or *availability bias* (Shepherd et al., 2018) wherein the level of risk is judged by the ease with which relevant changes in weather and extreme events come to mind. Witnessing the effects of extreme weather, such as flooding, is thus thought to increase awareness and concern about future impacts of climate change. The extent to which these findings apply to the farming population, however, is unclear and cannot be assumed given the social and cultural specificities of this group (Gasson and Errington, 1993; Burton, 2004) and evidence that risk perception is specific to culture and place (Taylor et al., 2014). Farmers have always had a particularly close and experiential relationship with the weather (Osborne and Evans, 2019) and, given the reliance of their livelihoods on weather and climate, they might be expected to be particularly aware of, and responsive to, changing conditions. The nature of their occupation may also make them more – or at least differently - sensitive to climatic changes compared to the wider population. Indeed, the limited evidence available suggests this is likely to be the case. For instance, whilst research with the general public has repeatedly shown greater concern around increasing rainfall/flooding than heatwaves/drought (Taylor et al., 2019; Harcourt et al., 2019), reduced summer rainfall/drought raises particular concern for farmers due to the significant risk it poses to crop yields (Tate et al., 2010).

Existing literature suggests that, in general, farmers are indeed aware of climatic changes, particularly in terms of extreme conditions and the impact of these on agriculture at the local level (Ricart et al., 2018). For instance, in a survey of farmers in Sardinia (Italy), Nguyen et al. (2016) found wide agreement that the climate is changing. In a cultural approach to the issue, Geoghegan and Leyson (2012) show how farmers in Cornwall (UK) were also conscious of changes, articulating their own climate knowledges through "weather and seasons, embodied and experiential knowledges, and farming practices" (p62). In fact, farmers appear to have a fairly accurate perception of climatic changes, most likely as a result of weather being so central to their occupation daily lives. In a recent study, Houser et al. (2019) found that many farmers in Iowa (U.S) could accurately identify climatic change over time, discussing both the increasing occurrence of droughts and heavy rain, as well as longer growing seasons. Similarly, Wiles (2012) established that UK farmers' perceptions of future climatic change were broadly in line with scientists' projections, regardless of whether or not they believed those changes were induced by human activity.

2.2. *Farm level adaptation to extreme weather and climate change*

Despite evidence establishing a broad awareness among farmers of changes to weather and climate, the extent to which they are responding to these changes is less clear, particularly in the UK context. As Osborne and Evans (2019, p. 213) state, "perception is not a sufficient condition for adaptation alone because the latter is a two-stage process of perceiving such risk then responding to it…. further research would be required to improve our understanding of farmers' adaptation to future climate risk". Indeed, research from elsewhere suggests a disconnect between perceptions and adaptation action among farmers (Ingram, 2014; Nguyen et al., 2019), with one of the few UK-based studies finding farmers poorly prepared (Tate et al., 2010). The reasons for this disconnect are complex, but explanations often centre on the issue of uncertainty when it comes to understanding and predicting future weather and climate change (Ricart et al., 2018; Nguyen et al., 2016; Käyhkö, 2019). Other research paints a more mixed picture, with the probability of adaptation varying according to a number of factors, including socio-economic attributes (Ingram, 2014) and farm size (Peltonen-Sainio et al., 2020; Stringer et al., 2020). Nguyen et al. (2019) also discuss the importance of understanding how different types of knowledge are implicated in driving farmer decision-making and action around climate adaptation. Their study of Italian farmers revealed that, whilst farmers' declarative (i.e. factual) knowledge of climate change influenced their attitudes towards its causes, it did not directly drive their adaptation practices. Rather, the capacity to act on adaptation depended heavily on procedural (i.e. knowing *how*) knowledge, which was constructed in relation to specific farm contexts and experiences, and often co-developed through various social networks. Although many of these studies suggest deficiencies in agriculture's general state of preparedness, its capacity to adapt and evolve in response to climatic changes remains unclear. Mechler et al. (2010)'s study looking at the historic economic impacts of extreme weather on UK agriculture suggests a more positive picture, as it concludes that farmers have autonomously adapted to extreme weather over time. The authors note, however, that responses have primarily consisted of 'low-hanging fruit' and question whether the adaptive rate can be continued into the future.

A large number of adaptation measures have been identified as being available and effective at building resilience at the farm-level, and these are beginning to be communicated to the farming community. These include the use of new technologies, farm and crop diversification, improvements to soil health and water management, and the use of different crop varieties or livestock breeds that are more resilient to climate extremes (Benton et al., 2012; EEA, 2019; Morison and Matthews, 2016; POST, 2019). If we are to ensure a resilient and productive agricultural sector in future, there is an urgent need to better understand farmers' attitudes towards these types of measures and the extent to which they are actually being implemented on farms, and to explore the challenges and barriers they may face. These questions formed the focus of our research.

3. Material and methods

The empirical research presented here formed part of a wider project funded by the UK Climate Resilience Programme, *Crop Monitoring and Modelling Network for Improved Predictions of Climate Impacts: CROPNET,* an interdisciplinary project conducted by partners from the Centre for Rural Policy Research at the University of Exeter, the Centre for Ecology and Hydrology, Lancaster University and Rothamsted Research. CROPNET aimed to engage users in the development of an interactive prototype tool for monitoring and predicting the impacts of extreme weather and climate change on crop and grass yields across the UK. Understanding potential users' (i.e. farmers, farm advisors and other industry specialists) experiences of, and attitudes towards, climate risks was viewed as an essential part of this process from the outset, and it is the qualitative findings emerging from this element of the project which are discussed here.

Farming in the UK is diverse, with a distinctive geographic nature to the pattern of farming systems. Recent decades have seen a broad polarisation between more intensive arable farming in the east and southeast of England, and pasture-based livestock systems in the west and north of England (and in Wales, Scotland and Northern Ireland) (Haines-Young and McNally, 2001). A gradual process of consolidation has also led to a growth in farm sizes and the average farm size in England in 2016 was 85.4 ha (Defra, 2018c), though a strong element of small family farming still exists in some (particularly livestock) areas[1]. This project focused on two case study regions: predominantly livestock farming in Devon (southwest England), and predominantly intensive arable farming in the Oxfordshire, Buckinghamshire and Berkshire area of southeast England. This approach enabled the issues at hand to be explored and understood within the context of place-based specificities (Stake, 2008; Yin, 2009), which in this instance include agronomically relevant characteristics such as soil type and local climate. Our study areas were chosen primarily for their contrasting predominant farm types, allowing the research to consider how climate adaptation attitudes and actions differ for different farming systems, whilst retaining an element of local specificity. The presence of strong farmer networks in these regions also enabled us to engage individuals with knowledge and experience of farming across the local area.

Taking a qualitative, semi-structured approach, the interviews were designed to provide deeper insights into how individuals experienced and made sense of the issues at hand in relation to their own lives and businesses (see Valentine, 1997). An interview guide was developed by the authors with input from the wider research team, which included individuals with expertise in a range of relevant topics, including soil science, agro-ecology and sustainable land management. As well as some closed questions which, for example, gauged participants' experience of specific extreme weather events and adaptation options, interviews included a number of open questions that could be tailored by the interviewer as appropriate, in order to prompt further deliberation and allow interesting points to be explored in more depth. The interviews were also informed by preliminary discussions with 23 stakeholders and 4 farmers at two workshops held in June 2019[2]. As well as gauging participants' interest in, and requirements for, a crop monitoring and prediction tool incorporating climate impacts (a prototype for which was developed as part of the CROPNET project), the workshops served as a start for gathering broad industry views on the risks and opportunities associated with climate change and extreme weather, and barriers to adaptation. This helped guide the selection of topics for discussion in the interviews.

In total, 31 in-depth, qualitative interviews were conducted with 15 farmers and 16 other stakeholders including farm advisors, consultants and industry representatives (referred to in this paper as 'stakeholders' for brevity). We adopted a purposive sampling technique for the interviews; a nonprobability sampling method that is used to select cases that are of particular interest to the research (Cresswell and Plano Clark, 2011; Schutt, 2006). This approach does not allow for generalisability of results but prioritises depth of understanding through gathering rich information from a relatively small number of participants (Patton, 2002). In our case, we interviewed a selection of stakeholders as well as farmers, not to compare and contrast their responses, but in order to draw on these individuals' extensive experience of a range of farm businesses, including those who may not typically participate in research of this sort[3].

The 15 farmers interviewed represented a range of farm types (5 arable, 2 sheep, 4 dairy, 3 mixed and 1 horticulture/arable), although for simplicity these have been split here into 'livestock' or 'arable' farmers according to their predominant enterprise type[4]. Participants represented a range of farm sizes (ranging from 21 to 3000 ha), but with a significant bias towards larger farms (10 out of the 15 were over 100 ha in size) and this is important to bear in mind when interpreting the results. Another relevant bias resulted from several of the arable farmers being recruited via an existing network, Achieving Sustainable Agricultural Systems (ASSIST), which places a particular emphasis upon soil health (a factor thought to increase resilience to some climate risks). As already noted, the nonprobabilistic nature of the sample thus cautions against making generalised conclusions in relation to attitudes and responses to climate risks across the whole of the UK agricultural sector, with our results over-representing larger, probably more economically robust, agribusinesses. The qualitative nature of the data, however, provides insight into a number of issues and experiences that are likely to be mirrored, or even accentuated, within the wider farming population. The 16 stakeholders interviewed were also able to offer broader perspectives on the UK agricultural industry (i.e. reaching beyond the individual farmers involved in the research), as they were familiar with the activities and experiences of a wide variety of farming systems[5].

Participants were initially recruited through existing contacts known to the project team, some of whom acted as gatekeepers to further participants. Interviews were conducted by a single researcher (RW) in the autumn of 2019, who was able to explore the research themes in depth with each participant and gain a full understanding of the data. Full written consent was secured for each participant and interviews were audio recorded for subsequent transcription. Responses to closed data were recorded in Excel, and data relating to open questions (which formed the majority of the interview schedule) were analysed inductively by interrogating the transcripts for common and meaningful themes, which were organised with the assistance of the computer software package Nvivo. The analysis was led by the interviewer and corroborated by another member of the research team (ML), thereby providing an element

[1] For more detail on the characteristics of UK farming and how it has changed, see Lobley et al. (2016).

[2] 10 stakeholders and 3 farmers who attended these workshops also participated an interview. Whilst potentially making these participants better informed about climate impacts, we do not believe this significantly influenced their interview responses, as the information presented at the workshop was predominantly generic and publicly available whereas the interviews focused on participants' thoughts and experiences at the farm level.

[3] Whilst we note the 'type' of participant being referred to throughout this paper in order to contextualise the responses being discussed, it should be noted that in reality the two categories are not discrete, as a number of the stakeholders were also farmers themselves.

[4] 7 farmers were based in Devon and 8 in the Oxfordshire/Buckinghamshire/Berkshire area. All were male and their ages ranged from 35 to 64 with an average age of 49, which is younger than the national farmer average of 59. Participants represented farms with a variety of tenure arrangements, including wholly owned, wholly rented and mixed tenure farms.

[5] All stakeholders had extensive working experience of the agricultural sector, with some having a broad overview of all farm types and others having specialist expertise in a particular sector, such as arable or dairy farming. Two stakeholder participants were female and the remaining 14 male.

of investigator triangulation. All data has been anonymised.

4. Results and discussion

4.1. Perceptions of climate change and extreme weather

4.1.1. Threats and opportunities

Most participants agreed, at least to some extent, that the UK climate is changing and that there is a need for agricultural businesses to adapt to the risks associated with extreme weather and longer-term climate change. However, perceptions about the relative risks and urgency of adapting varied considerably. When asked whether, overall, they viewed climate change as a threat or an opportunity for agriculture, participants were almost equally split in their responses, with around a third of both farmers and stakeholders seeing it as an opportunity, around a third seeing it as a threat, and a third seeing it as both a threat and an opportunity (one farmer said neither). Peltonen-Sainio et al. (2020) observed the same roughly equal split in opinion among Finnish farmers, suggesting that this balance in views is not unique to our study's particular context.

Participants were asked what they perceived to be the main risks and opportunities, either for their business (in the case of farmers) or for UK agriculture in general (in the case of stakeholders). The risks identified primarily centred around the impacts of more frequent and intense extreme weather, many of which they had already directly experienced or been witness to; in some cases very recently given that the interviews took place during an extremely wet autumn. These included the impact of heat and drought on crop and grass growth, with knock-on impacts for yield and winter animal feed, and the implications of heavy rainfall/flooding for soil run-off and erosion and for field operations such as drilling and harvesting. Opportunities, on the other hand, mostly related to more gradual, longer term climatic changes, such as increasing temperatures making novel crops (e.g. grapes, hemp) more viable and generally raising the productivity of crops and grassland. There was also a notable sense among both farmers and stakeholders that adaptation is necessary in order to seize competitive advantages over those who do not adapt. For instance:

> *"Some farmers are not building resilience into their system, but that's an opportunity for those that are. There's still a potential loss of output but if you can build a resilient system you can out-compete those who have not"* (Arable farmer 1)
>
> *"One man's threat is another's opportunity"* (Livestock farmer 2)
>
> *"Some will adapt better, but that will be at the expense of those that don't"* (Stakeholder 13)

This type of attitude is understandable from an individualistic point of view and chimes with Houser et al.'s (2019) 'political economy of relevance' approach that frames U.S farmers' climate perceptions as heavily influenced by the structural conditions of capitalist production. It is also arguably reflective of the farmers in our sample being particularly forward-thinking and business-minded and/or being in a better position to take advantage of opportunities. From a wider industry point of view, however, adapting to climatic change at the expense of others is not necessarily a desired outcome: rather, the aim should be to instil resilience across the sector – and wider food system - as a whole.

4.1.2. Levels of concern

When farmers were asked how concerned they were about the impacts of extreme weather on their business over the next 5 years, most displayed some level of concern about at least one type of extreme weather. In line with the concept of an availability heuristic (Tversky and Kahneman, 1973; Taylor et al., 2019), much of this concern appears to arise from impacts that have already been experienced at the farm level; both from heavy rainfall and hot, dry weather (see Section 4.2)

Several farmers also saw the benefits of preparing for these risks in the future and were taking a range of actions to do so (see Section 4.3). On the other hand, others saw less of an imperative to act. Whilst all farmers recognised the potential for farm businesses to be adversely affected by extreme weather and climate change, some said they were not particularly concerned about the risks to their business over the next 5 years (though note this did not necessarily mean that they were not taking actions to increase their business resilience). Their reasoning varied but included not seeing climate change as a serious or high-priority risk, seeing it as something outside of their control, and a desire to focus on the opportunities:

> *"There are more things in my control that I worry about"* (Livestock farmer 7).
>
> *"I always want to see the opportunities. A digitalised, better informed world, more flexible, dynamic world is full of opportunity to adapt and change and young people are right up for it"* (Livestock farmer 1).

The impacts of extreme weather and climate change over the longer term (10–20 years) were generally viewed as more significant, but since these lie outside the timeframes most farmers plan for (crop rotation plans for example usually only cover the next 3–5 years), few farmers were actively considering how they might alter their business practices accordingly.

4.1.3. Natural resilience and adaptive capacity

Farming has always been both dependent on and responsive to the weather (Osborne and Evans, 2019). Thus some participants portrayed extreme weather as simply a normal phenomenon, which has always occurred and which is part and parcel of farming:

> *"I'm not a sceptic but with so much on the news, you hear about everything from everywhere – I think extreme weather events are hyped up a bit. The weather's always changed"* (Livestock farmer 2).

Furthermore, a number of participants (both farmers and stakeholders) appeared relatively relaxed about climate change and extreme weather because they believed farming to be 'naturally resilient' and capable of coping with/adapting to the impacts or, in other words, of having a naturally high adaptive capacity:

> "*Farming appears to be naturally very resilient and will find a way to deal with it. Agriculture may not look the same at the end of it, but it innovates and does come up with solutions*" (Stakeholder 14).
>
> *"I can see small changes [in weather], but there are far bigger influences out there affecting us more. We'll just change our methods slowly to negate the risks"* (Arable farmer 4).

Some farmers also displayed a sense of stoicism in terms of *"taking climate change on the chin"* (Arable farmer 3) and farming *"to whatever gets thrown at me"* (Arable farmer 5). The significance of famer identities that emphasise masculine ideals (Alston and Kent, 2008) and competent farming abilities (Burton, 2004) may be at play here in terms of influencing a show of confidence in being able to cope with the effects of extreme weather and climate change, at least in the short term.

Whether this type of attitude is an indicator of well-founded confidence or potentially damaging complacency arguably remains to

Table 1
Impacts of extreme weather experienced by UK farms over the last 5–10 years.

Weather type	Negative impacts		Positive impacts	
	Arable	Livestock	Arable	Livestock
Heavy rainfall/ flooding	• Diseased grain • Waterlogged crops/ fields • Crop loss or yield reduction • Delay to operations (particularly drilling) • Soil runoff and erosion • Increased slugs	• Extended need for livestock housing • Reduction in grass growth • Poor utilisation of grass by animals • Delays to distribution of product • Silaging issues • Loss of livestock • Poaching • Contamination of grass due to polluted rain	None reported	None reported
Prolonged dry spells/ drought	• Crop loss or yield reduction (particularly wheat) • Poor quality crops - rejections	• Reduction in grass growth and lack of forage: o Cost of buying-in feed o Lower cow fertility o Premature culling o Reduction in milk yield o Reduction in livestock weights • Pressure on water sources	• Easier harvesting conditions • Reduced grain drying costs • Fewer pests & diseases (e.g. septoria, slugs)	None reported
Extreme cold	• Crop damage • Delay to operations	• Difficulties reaching livestock • Reduction in ewe milk: cost of buying-in lamb feed • Extended need for livestock housing • Livestock housing inadequate • Freezing pipes in dairy • Lamb losses • Reduction in grass growth • Wasted milk (due to no deliveries)	None reported	• Income from snow clearing
Extreme heat	• Crop poorly established • Crop loss or yield reduction • Drilling difficulties • Pests and diseases	• Cow heat stress – reduced fertility • Reduction in grass growth *(impacts as for drought)* • Increased rates of mastitis • Higher poultry mortality • Personal discomfort	• Fewer pests & diseases	None reported
Stormy/windy weather	• Crop damage • Building damage • Trees/branches blown down • Delay to operations - spraying	• Building damage • Power disruption • Trees/branches blown down	None reported	• Wind turbine
More gradual changes to climatic averages	None reported	• Cold spells appear to come later, shifted from mid-January to mid-March = livestock housed for longer • Increased flies	• Warmer temps beneficial for productivity • Fewer frost issues • Drier beneficial for historically wet areas • Drier beneficial for operations	• Benefits for animal health from more sunshine – increased vitamin E and B12

be seen. It does, however, contrast with the views of several stakeholders who believed that, despite some farmers becoming more aware of the risks as a result of recent extreme weather events (particularly the hot, dry summers of 2018 and 2019 and the very wet autumn of 2019), the UK agricultural industry in general lacks resilience, with worrying numbers of farmers unaware and unprepared:

> "*I worry that the vast majority will carry on as before but expect a different result. Climate change gives even more reason to change. They're not at all resilient*." (Stakeholder 1).

Melcher et al's. (2010) conclusions about the low-hanging fruits of adaptation having already been picked further caution against a complacency based on having coped with past impacts from extreme weather. If farming systems are to remain resilient into the future, adaptation must be seen as an on-going evolving process of planning and responding, a building of adaptive capacity from a systems perspective (Adger and Vincent, 2005), rather than an isolated task to be completed.

4.2. Observed impacts

Farmers were asked whether their farm had been positively or negatively impacted by a range of types of extreme weather over the last 5–10 years. All had been negatively affected by at least one weather type. Furthermore, whilst some did cite positive impacts from extreme weather, the overwhelming majority of impacts were negative. Stakeholders also offered numerous examples of where farms had been affected by extreme weather in recent years. The impacts cited by both farmers and stakeholders are summarised in Table 1, which demonstrates that the effects of extreme weather are both variable and wide-ranging, even among a relatively small number of farms. These impacts are not presented in any particular order in terms of frequency cited or overall severity, as the small size of our sample precludes any generalizable conclusions being drawn from such data. Negative impacts from dry weather on grass growth and forage availability for livestock farmers were, however, particularly common (a finding also observed by Salmoral et al., 2020); as were negative impacts on crop yields from both heavy rainfall and drought for arable farmers.

Whilst the severity of impacts varies widely, with some (e.g. storm damage to trees) causing only relatively minor inconvenience, extreme weather can have a significant impact on profit margins for farms, resulting in large remedial costs, raising production costs and/or reducing yields. For example, one farmer said that the dry summer of 2018 resulted in a shortage of winter feed for their cattle, reducing their margin for beef by 15–20%. Another said that the wet winter of 2012/13 reduced their winter wheat yield from 8.5 tonnes per hectare in an average year (and 11 in a good year) to 6.5 tonnes per hectare. Such figures should not be looked at in isolation, however, as some farmers pointed out that the financial costs of extreme weather can be balanced by the market. One arable farmer, for instance, reported how they had had poor yields of winter–sown crops in 2018 (due to a wet spring followed by very dry summer) but the prices *"went through the roof"* so their profitability remained unaffected. Similarly, two dairy farmers mentioned that although they incurred significant costs from buying in feed (due to poor grass growth) in 2018, they received higher prices for the milk due to a drop in global production, which to some extent compensated for the costs. Reductions in milk yield across the UK due to increasing heat stress over the coming decades have been predicted to have a significant negative economic impact, particularly in South West England (see Fodor et al., 2018), but these examples demonstrate the difficulties of making such predictions in the context of a highly globalised agricultural market where yield loss (or gain) does not necessarily equate to price loss (or gain). It also suggests that the impact of climate change at an individual business level may not be sufficient to drive adaptation.

Although there is commonality in the impacts experienced by different farms, a number of stakeholders in particular stressed that the nature and severity of impacts are very business specific. The farming industry is extremely heterogeneous and there are a number of factors that will influence how a farm is affected by any particular weather event, including farming system, geophysical features, and business acumen of the farmer. For instance, the dry summer of 2018 meant that some farms in wetter areas (e.g. North Devon) actually had better years than normal because they still had enough rainfall and benefitted economically from those in dry areas doing less well. Soil type and depth can also affect vulnerability to drought (and conversely waterlogging and run-off) due to variations in soil moisture holding capacity (Jain et al., 2015). Farm size is likely to be another relevant variable, although it is unclear how this relates to resilience: one stakeholder suggested that small farms may be more resilient than larger farms because they tend to have more varied enterprises and have more flexibility than large farms due to not being as tied to, or hindered by, large scale investments and complex management structures. Others, however, argued that generally lower profit margins restrict small farms' ability to invest and implement adaptation measures. Previous studies have also suggested that large farms may find it easier to adapt than small farms (Tate et al., 2010; Peltonen-Sainio et al., 2020), and indeed to adopt new practices generally (Doran et al., 2020; Prokopy et al., 2008), but further work is needed to investigate these conflicting claims and to establish and understand potential relationships between farm size and climate resilience.

4.3. Adaptation responses

As already noted, there was a general recognition among most participants, particularly stakeholders, about the need for farm businesses to adapt and build resilience to the risks of extreme weather. And indeed, many farming participants were taking a range of actions designed to improve the resilience of their business, although not necessarily just for reasons associated with climate. Such proactivity was not always the case, however, with some farmers taking a more relaxed attitude to the issue, being unsure about what action to take, and/or feeling constrained from implementing the measures they would like to (see Section 4.5).

The wide array of adaptation measures participants had already taken to prepare their business for the impacts of extreme weather and climate change are summarised in Table 2. As with Table 1, these are not listed in any particular order, as the table is intended to portray the breadth, rather than frequency, of activities being undertaken. The efficacy of the particular measures implemented by interviewees is difficult to determine without further research (and the passage of time) but, in general, those cited do align with the types of interventions recommended in relevant guidance and literature (e.g. EEA, 2019; Morison and Matthews, 2016; Rial-Lovera et al., 2017; Wreford and Topp, 2020), as well as with those advocated by experts from the Centre for Ecology and Hydrology and Rothamsted Research who formed part of the research team.

Few farmers described themselves as directly adapting to climate change but most did see themselves as taking positive steps to respond to the risks of extreme weather and/or to generally improve their business resilience. For a number of farmers this primarily took the form of improving soil health, with participants aware of how this would help soils - and therefore productivity - to cope better with both wet and dry conditions. As one farmer explained:

> "*We're working towards improving soil structure etc., which is good for us whether the climate changes or not, for nutrient-holding capacity, water drainage and retention etc. Your soil is the biggest living thing on your farm*" (Livestock farmer 7).

As this quote suggests, many of the actions discussed by farmers were not being driven solely, or even primarily, by the need to adapt to a changing climate. Improving soil health was seen as a way of improving productivity regardless of weather/climate, and other actions were also described as part of a more holistic, sustainable approach to farming generally:

Table 2
Actions already being taken by farmers to improve resilience to climate risks.

Type of action	Arable	Livestock
Infrastructure improvements	• Farm reservoirs for rainwater harvesting • Grain dryer • Replacing machinery with larger than currently need (to ensure can take advantage of smaller weather windows)	• Extra livestock housing • Ventilated housing • Cow tracks • Slurry storage • Back-up power generation • More robust structures • New milking parlour to optimise resilience from grazing • Fencing and multiple gateways to reduce poaching
Soil health improvements	• General soil focus • Increasing organic matter • Cover crops • Direct drilling • Controlled trafficking • Min/no/strip till	• Focus on soil chemistry • Re-seeding • Nutrient application
Risk-spreading, business planning and efficiencies	• Mix of enterprises (e.g. arable and dairy) • Multiple income streams (incl. agri-environment schemes) • Diversification • Wide rotations/mix of winter & spring sown crops • Cropping plans (range of crops, maturity dates, variety choices)	• Mix of enterprises (e.g. arable and dairy)
Grazing/feed management	N/A	• Forage/feed budgeting • Extensive or reduced stocking rates • Mob grazing • Changes to grazing regimes
Operational timing adjustments	None mentioned	• Fly-spraying pre-sheep shearing • Weaning lambs earlier • Silaging earlier
Choice of varieties/livestock breeds	• Testing out new crops e.g. soya • Testing new varieties in a single field • Growing less oilseed rape • Always looking out for new varieties	• Maize with short growing season • More fodder beet (as will withstand drought) • Selected grass varieties • Planting coxfoot • Using Artificial Insemination to control breeding and reduce cow size (so need less forage) • NZ breed of sheep
Business planning and efficiencies	• Reducing labour • Farming to yields (rather than pushing for more)	• Logistical planning for power/transport disruption • Benchmarking and budgeting
Other	• Agroforestry • Improving biodiversity • Use of growth regulators (to reduce flattening of crops) • Silt traps	• Returned to lambing indoors (having tried outside to cut costs) • Direct selling/shortened supply chains

"It's good cow husbandry and good soil husbandry. Some crops are what's best for the soil fertility and nutrient management, and some are better nutritionally for the cows. So it's a balance; healthy soils, healthy animals, not having surplus nutrient runoff. It's a holistic balance" (Livestock farmer 4)

Efforts to improve productivity were also behind other actions that were recognised to simultaneously increase resilience to climate risks:

"We're operating a cross-breeding programme to get more resilience into cows. That's primarily to do with health traits but it does make them more resilient to temperature fluctuations and weather extremes as well" (Livestock farmer 4)

Reducing costs and generally increasing business efficiency (particularly in the context of uncertainties around Brexit and future subsidies) was another key driver for some of the actions and, as one farmer admitted (and as other research has affirmed internationally, e.g. Liu et al., 2018), it is this consideration that frequently lies at the heart of farmer decision-making:

"Other drivers are soil health. Well that's what I'm supposed to say isn't it, but the cost of production is really what's driven me down the route of controlled traffic and direct drilling – the costs are driven down" (Arable farmer 5)

Other drivers mentioned by farming participants included consumer/supply chain demands for sustainably-produced foods, the loss of some crop protection products, and preparing for suspected future legislation.

4.4. Future plans for adaption

When asked about whether they had any plans to make further changes to increase resilience to climate risks over the next 5–10 years, a common response from farming participants was around continuing to focus on soil health (a similar finding has been reported among farmers in Finland; see Peltonen-Sainio et al., 2020). Several farmers were also looking to expand their business in order to increase profits and economies of scale, and a few mentioned continuously evaluating their choice of crop/grass variety and growing techniques. Other actions included additional livestock housing, slurry and water storage, and risk-spreading through enterprise diversity.

For the most part, however, future plans were relatively vague and not designed primarily with extreme weather or climate change in mind. In a study of (livestock) farmer responses to the 2018 UK drought, Salmoral et al. (2020) observe a lack of long-term strategies to adapt to such conditions, and to a certain extent this was mirrored in our findings. Some farmers felt there are more urgent issues to consider and/or that there is too much uncertainty around climate change to plan for it now. Two farmers who were nearing retirement age commented that it would be more of an issue for the next generation than themselves. Despite this, however, when asked about how likely they were to carry out specific adaptation actions in the future (e.g. improve farm infrastructure, improve pest & disease management, alter choice of crop/grass varieties), many farmers did say that they were considering undertaking some of these and/or planning to progress improvements already underway in these areas. This finding affirms that some farmers are implementing actions with adaptation benefits but, since these are primarily motivated by other drivers, they are not consciously linking them with climate risks. As Käyhkö (2019) found in relation to Nordic farms, adaptation at the farm-scale is often an emerging rather than deliberate process.

4.5. Barriers to adaptation

There was general agreement among participants, particularly stakeholders, that a range of practical factors (predetermined by the research team) were likely to pose barriers to adaptation for at least some farms. These included: a lack of finance; a lack of information about how to adapt; and a lack of time. However, for many of those farmers interviewed, these did not appear to pose significant barriers, with a number of more subtle or complex barriers emerging as potentially more significant. These are discussed below.

4.5.1. Uncertainty

A key issue arising throughout the interviews with both farmers and stakeholders was that of uncertainty in relation to future changes in climate and the impact on individual farms. Whilst there appeared to be a general acceptance that the climate is changing, there was a sense that uncertainty around the exact scale, speed and nature of change at the local scale makes it difficult to plan:

"There's lots of talk about what's going to happen but it's a bit like Brexit – until we get there we don't know what's going to happen" (Livestock farmer 7).

"I'm interested in managing what we're confronted with. Even the climate change experts, if you asked them for a confidence limit on what is going to happen on any individual farm, they'd struggle. We know it's a heightened risk but it's whether it's going to hit that farm or not" (Stakeholder 7).

Whilst farmers were generally willing to change their practices and try new things, this was often dependent on having confidence in the benefits of doing so. Where these are uncertain, the risks are higher and farmers will understandably be more reluctant to make changes:

"The risk word is important. Why aren't I planting new crops? It's the risk of not knowing if it's the right thing to do" (Arable farmer 6).

Participants also expressed uncertainty about how changes to the climate will interact with, or be balanced by, other (equally uncertain) changes, again restricting farmers' ability to plan:

"I suspect they're conscious of the extremes because that will impact on how to manage crops. But the challenge is how they forecast/ manage based on longer term climate change. There's a lot of unknowns. That's not to say they shouldn't be doing it but there's a lot of questions. Will there be new crops I can add? Will new varieties be adapted? And there are other factors. What's the demand for the crop? Will it be profitable? Are there pests and diseases that will become more or less important? There's lots of variables" (Stakeholder 3).

Uncertainty as a barrier to acceptance of, and adaptation to climate change, is a common finding among the general public, as well as farmers (Ricart et al., 2018). There is no easy solution to the issue, but building the adaptive capacity of agriculture as a whole through improving technology, information and knowledge relating to adaptation actions and business planning, is likely to be key to improving farm-level resilience irrespective of individual attitudes to climate change (Hall and Wreford, 2012; Ingram, 2014; Nguyen et al., 2016).

4.5.2. A low priority

A recurring theme emerging from farming participant accounts regarding their reasons for not already having taken significant adaptation action was that the issue is simply not seen as a priority in the context of time pressures, more immediate imperatives and/ or wider challenges facing the business. In some cases, farmers did not necessarily dispute the benefits of taking action to prepare for climate-related risks, but felt that they did not have time to think about and address the issue sufficiently. Some *"hadn't got around"* (Arable farmer 5) to certain measures they would like to undertake, whilst others were *"concentrating on the short term"* (Arable farmer 2). Since climate change is frequently seen as a long-term issue, other concerns can take precedence in farmers' minds (see also Wiles, 2012; Hall and Wreford, 2012). More immediate concerns cited by participants included 'the loss of actives' (i.e. certain types of herbicides and pesticides), flea beetle infestations in oilseed rape, and imminent changes to the subsidy support system as a result of Brexit.

In other cases, adaptation was not seen as a priority because they were relatively unconcerned about the impacts of climate change and saw political and public pressures as more significant:

"I'm not concerned. I don't see it being the biggest driving force for what we have to deal with, it's more political and market driving forces, political change that's more worrying" (Arable farmer 4).

Such views underline findings from studies in North America (Houser et al., 2019) and Colombia (Eitzinger et al., 2018) in which farmers also emphasised the importance of political-economic pressures on their decision-making and practices. Ultimately, the challenges presented by climate change are not experienced in isolation from other factors and it is no surprise that farmers perceive climate change in the context of other risks affecting their business. Overlooking such interdependencies in any effort to support or encourage greater action within the sector is unlikely to lead to resounding success. Uncertainties around the extent and severity of future climate also inevitably affect the weight of importance placed on addressing the issue by farmers, particularly in the absence of other drivers. As one stakeholder said, *"there's no policy direction, no market direction, no market signal, like there is with net zero. Farmers are not seeing it as a big enough trend yet"* (Stakeholder 10). The call for stronger policy and industry leadership is clear.

4.5.3. Market demands

Uncertainties and the relevance of other factors also come to the fore in relation to farmers' long-term business planning and attitudes towards enacting specific adaptation options. We found that some farmers were reluctant to change their enterprise system or to grow different crops because they are not confident that there will be a sufficient market for them. For instance:

"I would love to move to mixed farming but financially it doesn't make sense. I'd like more cattle - corn and horn - but it's not profitable. I'd like to because it gives a spectrum of diversity, I get nutrients out of it. I need more shit! I currently import about 200 tones chicken litter, plus manure… but the price of beef is too low, I'd lose £200 per cow. I do venison here on natural breeding cycles and the price has dropped by 30% this season. Red meat is not working, the public is poorly educated" (Arable farmer 4).

"I could grow crops more suited to the climate but I need a market for them. [For example] I could grow soy for flour but no one is interested in milling a small amount" (Arable farmer 2).

"I'm considering agroforestry but not enough is known about the true benefits. And the economic benefits - the market for fruit, timber etc. – the economic drivers aren't there" (Arable farmer 1).

Market uncertainties are particularly pertinent at the current time in light of public discourses around shifts away from meat and dairy consumption, and changes to trade systems following Brexit. Making significant decisions around enterprise focus is therefore particularly challenging, and potentially risky, at present. The extent to which some enterprises and management practices may or may not be incentivised under the forthcoming E.L.M programme (due to be introduced by the UK Government in 2024) is also unknown and may in some cases be leading to farmers delaying activities (e.g. tree planting) in case payment is offered for them in future.

4.5.4. Business planning

The tendency for many farmers to focus on the short-term also relates to what several stakeholders see as poor business planning within much of the industry. A number of stakeholders talked about many farmers generally being reactive to climate-related issues, responding either in the moment or according to 'what happened last year' rather than being proactive and planning. As one participant put it, farmers *"are just responsive to the situation as it comes along rather than planning for a bad year. Nobody plans for a bad year, everyone plans for a good year"* (Stakeholder 5).

The importance of business planning was repeatedly stressed by stakeholders. For example:

> *"Farmers need to have a plan and to understand why they are planning. Business planning in agriculture is very poor at the moment"* (Stakeholder 15).

Some respondents suggested that many farmers lack awareness about how to prepare for climate-related risks, and about what the cost-benefit ratio is likely to be from implementing adaptation measures. Stakeholders in particular took this view when thinking about farmers in general:

> *"There's a lack of quantifiable information on the benefits of adapting. What information there is, for instance on different crops, tends to be a snapshot of what the crop produces rather than in the context of the wider farming system. Farmers need to know the net result for their particular farming system. We need a systems approach to resilience"* (Stakeholder 11).

Chiming with Harcourt et al. (2019)'s finding that members of the general public are hindered from taking individual action to adapt to climate change due to a lack of knowledge about available options, farmers are not always sure what they can do *in their specific* circumstance to adapt to climate risks. Self-evaluations of appropriate skills and knowledge are integral to perceived behavioural control and a sense of agency, which have been repeatedly shown to be crucial in farmers' adoption of 'best practice' (Doran et al., 2020; Inman et al., 2018). Increasing farmers' self-assessed capacity to act must therefore focus on supporting them to develop procedural (knowing-how) knowledge about climate resilience within the context of their own farm and daily practices (see Nguyen et al., 2019). Thus, whilst it may be impossible to offer individualised information to farmers on a large scale, there is clearly a need to offer tools and support that take into account the specificities of different farming systems and that can be easily tailored or interpreted to help farmers understand what climate change means for their particular farm and, crucially, what they can do to increase their resilience to both extreme weather and longer term climate risks.

4.5.5. *Investment constraints*

Of course, even if a farmer has identified actions or strategies that would help improve the resilience of their business, this does not mean they can or will be implemented. Cost-benefit calculations and other economic factors are key considerations. A lack of ability to access financial capital in order to make long-term investments in adaptive measures was highlighted by both farmers and stakeholders as a crucial barrier to increasing business resilience for many farms. Farm reservoirs, slurry lagoons, livestock housing, solar panels and tree-planting were all mentioned by various farmers as being desirable but currently too expensive for them to implement. Some of those with greater investment capability, however, were able to take a longer-term view on their expenditure. For instance, one farmer was experimenting with intercropping despite it currently not being beneficial economically because they were *"thinking ahead for what will be appropriate"* (Arable farmer 3). Another had recently bought drilling and harvesting machinery that were bigger than they needed because they wanted to be able to *"catch weather windows"* (Arable farmer 2). Current profitability or lack thereof is thus a crucial enabler/barrier to adaptation: *"if you're not making any money, you're not able to adapt"* (Arable farmer 2).

4.6. *Enabling adaptation*

Significantly, despite widespread assertions about the importance of economic considerations, when asked about a range of potential enablers for on-farm adaptation, participants did not always support financial measures. For instance, the idea (presented to participants by the interviewer) of providing farmers with financial support to cope with market volatility (e.g. through favourable interest rates or tax breaks) was felt by some participants (both farmers and stakeholders) to risk creating a dependency upon this support, rather than incentivising better, more sustainable business practices that would increase resilience and adaptive capacity. The idea of increasing availability of insurance against weather-related risks (e.g. to cover crop losses) was met with similar scepticism. The suggestion of direct funding for specific capital projects that would improve resilience (e.g. farm reservoirs and ventilated livestock housing) was generally met with stronger approval in recognition that many farms lack the capital to make necessary investments. Such funding, whilst likely to be necessary for stimulating action across the industry, must therefore be carefully thought through. Any type of financial support is also bound to be accepted slightly begrudgingly by many who would rather farms were profitable enough to *"stand on their own two feet"* rather than have to rely on funding schemes or subsidies.

Adaptive measures that focus on enabling practices that increase productivity/profitability (often the primary motivating goal for farmers) and holistically enhance the resilience of farm businesses (e.g. improvements to soil health) may be more warmly welcomed than direct finance. Accordingly, the most strongly supported potential enablers discussed with participants were around facilitating learning (particularly through farmer-to-farmer learning via demonstration and/or discussion groups) and helping farmers to access high quality, coherent, customisable information and advice about climate risks, ways to improve resilience, and the costs and benefits of appropriate adaptation options. We strongly concur with Nguyen et al. (2019) and Ingram (2014) that respecting farmers' existing knowledge, values and experiences is essential in this process. Informal, reflexive social learning that intersects with institutional knowledge but ultimately occurs within groups has been shown to be key in building cross-sector local adaptive capacity to climate change (Pelling et al., 2008). Concurrently, co-productive or participatory engagement approaches that build on existing social networks and local knowledge bases are most likely to be able to utilise and enhance the potential 'natural resilience' or inherent adaptive capacity of agriculture that was pointed to by some of our participants.

5. Conclusions

The empirical evidence discussed in this paper suggests a mixed picture of resilience to climate risks within the UK farming industry. It is notable that all interviewees had already experienced or witnessed negative impacts from extreme weather events in recent years and were conscious, at least to some extent, of the likelihood of such impacts occurring again in future. That heavy rain (along with heat and drought) was the weather type of most concern is perhaps unsurprising given that the interviews were conducted in the midst of extremely wet weather in Autumn 2019, but – in line with the concept of availability heuristic and research among the general public (e.g. Harcourt et al., 2019) - it is indicative of how awareness about such risks may be increasing as extreme weather becomes more frequent and extreme.

Despite this recognition and experience, many in the industry are concerned that too few farm businesses are not taking sufficient action to increase their business resilience to extreme weather and climate change. Many farmers do not perceive adaptation to be a priority and view the risks as either too uncertain and/or too long-term to warrant any significant investment of time or money at present. It is easy to see why this is the case given the array of other challenges and uncertainties facing the industry, with many farmers understandably preoccupied with short-term profitability and business survival. Hence, where we might expect the episodic memory of events to be driving farmers to adapt (see Shepherd et al. (2018)), it appears that more pressing issues and capitalist concerns (see Houser et al., 2019), as well as a persisting sense of uncertainty (regarding both climatic and economic scenarios) are restricting this potentiality. Certainly, both farmers and stakeholders discussed a range of issues and barriers that are constraining improved resilience across the industry, including some lack of awareness about the type and cost-effectiveness of potential adaptation options.

More positively, our findings revealed a sense of optimism among some farmers and stakeholders around the potential opportunities posed by climate change and farming's ability to adapt and respond to changing conditions as they occur. Several participants were keen to stress the inherently innovative, adaptive and resilient nature of the industry. We also found encouraging evidence of positive actions being taken by many, if not all, the farmers we spoke to, whether in direct response to climate change/extreme weather or as a result of other drivers such as soil health, policy and legislation, cost reduction, productivity and changing consumer demands.

This research has provided greater insight into how a range of farmers and wider industry stakeholders perceive some of the impacts, challenges and opportunities associated with extreme weather and climate for UK agriculture. Whilst there are many innovative and exciting activities happening on farms across the country, there is still much to be done to improve the resilience of individual farms and the industry as a whole. There is a need for further research, including larger scale surveys designed to produce more generalizable results. As we have seen, there appears to be a farm size dimension to both vulnerability and adaptive capacity but more work is required to fully understand the role that farm size plays. If we are to design effective interventions that help farmers adapt we also need to be better informed about how they conceptualise climate change and the implications of this for their disposition to adapt. There is also an important need for longer term research to explore the efficacy of farm-level adaption measures. Demonstrating the efficacy of individual measures will help remove some of the uncertainty around climate adaptation.

Government policy can play a role in facilitating adaptation and addressing some of the issues identified in this research. For example, whilst details are yet to emerge, grant aid is expected to be available as part of Defra's (2020) proposed Farming Investment Fund, which is designed to improve profitability and benefit the environment. Eligible items will include on-farm water storage infrastructure, for example. Defra's flagship E.L.M programme will also help support adaptive measures such as improved soil health. Other opportunities to support adaptation beyond this must be grasped too. Many of the potential enablers we discussed were strongly supported by interviewees, with improved industry collaboration, farmer-to-farmer learning, and better communication of context-specific information about responding to climate risks seen as particularly crucial to increasing resilience within farming. We must not forget, however, that the agricultural industry is markedly heterogeneous and the ways in which businesses are affected by, and responding to, extreme weather and climate change vary hugely from farm to farm. The resilience, adaptive capacity and needs for advice and support among farm businesses are thus highly context specific and there is no 'one answer fits all' to questions of climate change impacts and adaptation in UK agriculture.

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Due to ethical concerns, the research data supporting this publication are not publicly available.

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