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REFEREED ARTICLE

CHANGES TO FARM BUSINESS MANAGEMENT UNDER EXTREME WEATHER EVENTS: LIKELIHOOD OF EFFECTS AND OPPORTUNITIES IN THE UK

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Focus groups were held in the UK to consider the potential adaptation of farming systems to cope with climate change towards the year 2020. The findings were combined with MET office data and the results from a survey of 12000 holdings. It was found that agriculture is neither well prepared nor well informed about climate change. A list of potential adaptations was tested for financial viability using partial budgeting and discounted cash flow techniques. Whilst the impact of climate change typically had a cost implication, the benefits were often qualitative, for example enhancing animal welfare.

Key Words Climate change, extreme weather events, adaptation, partial budgeting, discounted cash flow, financial viability.

Introduction

Warming of the world's climate system is happening largely due to the increased emission of green house gases (GHG) (IPCC 2007). Some of the world's largest polluting countries such as the United States have not been the most active in controlling their emissions, although this is likely to change with the changing administration in the USA (Harris, 2009). The role of the land based industries worldwide in GHG mitigation is acknowledged in the academic literature. This takes a number of forms. The enormous potential offered from the slowing of deforestation, particularly in South America, against the limited potential offered by forestry planting is a familiar issue, although it has been accepted that the likelihood of a deforestation slowdown is low (Fearnside, 2000). The scope for bioenergy for heat and electricity generation would also have some mitigating effect though the plans for this are rather modest in the UK (Taylor, 2008; Defra, 2007). It should also be noted that there is evidence for some potential benefits to the land based industries of increased GHG and associated global warming such as increased growing season and a decline in frost damage to crops and machinery. In applying scenario planning techniques the short and medium term effects on world production of livestock, crop and forestry outputs are all positive, but the impact of associated ozone and ozone precursors such as methane in the long term provides severely negative effects (Reilly *et al*. 2007).

The UK Government is committed to successful adaptation to climate change and as a result has commissioned several studies to examine how this adaptation might happen. This study was prepared by ADAS over a three year time period commencing in 2005 and was the first study to focus on the nature and potential for pro-active adaptation to extreme weather events (ADAS, 2008). There have been several studies that have warned of the need for adjustment (Orson, 1999; Shepherd, 2001; Holman and Loveland, 2002) and the form that this might take (MAFF, 2000; IGER, 2002) but little involving farmers. This Defra funded project was commissioned to remedy this and to develop a consensus across the industry on costed, practical and worthwhile adaptations that would deal with the existing drivers for change.

Selection of Variables of Climatic Extremes and Industry Sectors

Although connected with climate change and global warming, climatic extremes are rather aspects of these phenomena but not the whole story and have their own terminology. Climatic extremes have been defined internationally and principally with extremes being defined as performance that lies outside of the 10th or 90th percentiles (IPCC, 2001). For the purposes of this research this is interpreted as firstly the extreme weather event which in a normal distribution of weather data such as maximum daily temperature is defined as an event outside of the 10th or 90th percentiles. An example would be the maximum daily temperature data for England which reached 38^{o} C in the summer of 2006. The second is the extreme climate event, where a number of extreme weather events happen over time. An example would be the hot summer of 1995 which was 3.4^{o} C warmer than the 1961-90 average. In other areas of the world researching the local impact of global warming, such as the Swiss Alps the interest is in temperature extremes and rainfall extremes. Work done on these harnesses the same IPCC definitions of extremes as used in this project, examining performance that again lies outside of the 10th or 90th percentiles (Beniston, 2007).

The issues for consideration revolved around the potential for adaptive behaviour by farmers in the event of extreme weather events reaching a critical frequency and the possibility of extreme climate events becoming more frequent.

The project was focussed on the relatively short term climate change that is forecast to take place in the next 15-20 years. The years 1995-2005 was the base period under investigation for weather extremes, thus notably the hot summer of 1995, wet autumn/winter of 2001 and the hot summer of 2003 were included as they were inside of the project reference period. These extremes were summarised in Table 1

The objectives of the project were:

1. To assess, using MET Office data and analysis, how the frequency and magnitude of the main extremes may change in the future under climate change to the 2020s and how well such changes may be predicted;
2. To determine with agricultural stakeholders the main extremes that will affect agricultural production;
3. To determine with the industry, how it will adapt to these changes within the context of existing land use change drivers and projections of future socio economic change;
4. To provide a range of costed adaptations to extremes which covers a spread of agricultural sectors, regions and broad soil types;
5. To produce a final report providing examples and a timescale for inclusion of these adaptations into farm business and industry development plans.

Table 1-Summary of the chosen extreme and its definition:

Threshold/extreme	Definition
Heat wave duration/timing	It is defined as the total length of periods of at least 6 days, during either the summer half-year or winter half -year, when the maximum temperature exceeds the 1961-1990 average for that day by at least 3°C and Julian day of start of heat wave.
Frequency of occurrence of maximum temperature exceeding 32°C for >10 days	Number of occurrences of maximum temperature exceeding 32°C for more than 10 days.
Growing season start and end dates	Date of start and end of growing season where the growing season is assumed to start on the 5th consecutive day with a mean temperature of 5°C or greater and end on the 5th consecutive day with a mean temperature of 5°C or less.
Frequency of frost days per month	Number of days with minimum temperature < 0°C.
Duration and timing of dry and wet periods	Greatest number of consecutive days where rainfall < 1mm or rainfall >1 mm and the start date of period.
Simple Daily Intensity Index	Quotient of amount of days where rainfall > 1mm and number of days where rainfall > 1mm.

This article is arranged in a further four main sections. The first of these describes the methodology adopted by the project team to meet the above objectives, the second gives the results arrived at and the third section discusses the findings of the project along with published academic literature. The final section provides some conclusions and implications of the findings of the project.

METHOD

Met Office Analysis

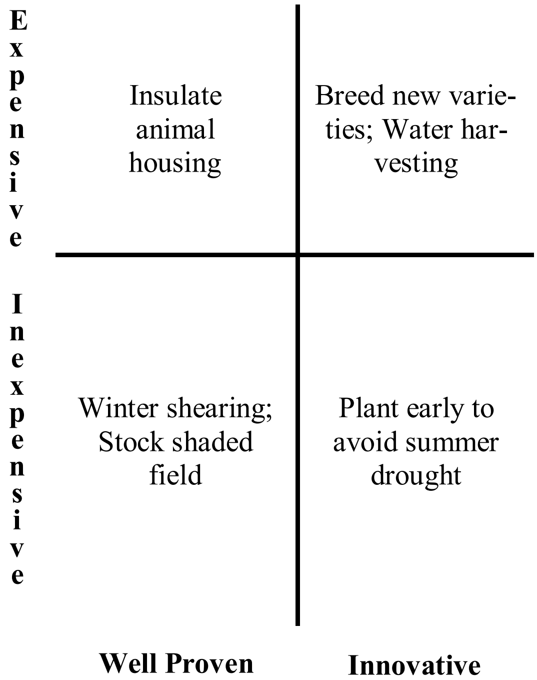
Climatic extremes were projected forwards for the 2020s relative to the 1970s using the Met Office's Hadley Centre Regional Climate Model, HadRM3. This was done by making projections for the 2080s and then by scaling these projections using methods described in Hulme *et al*., (2002).

Several hundred potential adaptations to the MET office forecast climate extremes were identified from sources including expert assessment and from various literature sources. Figure 1 shows the classification of these potential improvements in terms of level of expense and degree of innovation employed.

Farmer Focus Groups

Six focus groups with between six and eight farmers per group were held at regional centres throughout the UK between 26 January and 13 February 2006. The purpose of the focus groups was to consider the types of extreme

Figure 1- Illustration of the range of complexity and expense of adaptations options considered



weather experienced in the period under investigation and the impacts of that weather upon farming practices. The membership of the focus groups was drawn from a range of farm types and enterprises that reflected the regional location of the group.

A summary of 124 adaptations that appeared suitable for a detailed financial evaluation was compiled. These were then put to a second round of six focus group meetings held in March and April 2007 at the same six centres as the previous focus groups. Not all 124 adaptations were considered by all focus group meetings, nevertheless the farmers involved were prepared to consider most of the adaptations should the need arise, which was thought to be between 2 and 5 years of largely consistent weather, operating in an autonomous way.

ADAS Farmers' Voice ™ Survey

A randomly drawn sample of 12,000 holdings is drawn annually from the ADAS Farmers' Voice ™ database of approximately 47,000 holdings and a questionnaire posted out that for the years 2005, 2006 and 2007 included questions addressing issues of climate change. In 2007 2,000 survey forms were returned and as in previous years these were weighted for Government Office Region and farm size and type for each region surveyed, providing a stratified, randomised sample representative of the population of UK farmers.

Costing of Adaptations

A panel of ADAS specialists with many years of business advisory experience was convened to reduce the list of potential adaptations to 28, this being a number that could be assessed quantitatively within the resources allocated to the project. This reduction was carried out by a team that applied a number of criteria to the selection process on the basis of such factors as the importance of farming sectors and being representative of a range of climate extremes.

Information was assembled to enable detailed enterprise costing. This included detailed descriptions of current enterprises, impacts of the respective extreme events on enterprise performance, estimates of capital costs for adaptations and the impact that adoption of the adaptation would have on enterprise performance.

Figure 2-Structure of the partial budgets

Extra costs as a result of the adaptation, as compared to no action	A	Costs saved as a result of the adaptation, as compared to no action	C
Income lost as a result of the adaptation, as compared to no action	B	Extra income as a result of the adaptation, as compared to no action	D
Sub-total	A + B = X	Sub-total	C+D = Y
Impact on Profit	Y – X		

This was then formatted using a partial budgeting layout to show whether the adaptation was profitable or otherwise. This is shown in Figure 2. If Y is less than X then change is profitable, whereas if X is less than Y then the adaptation is unprofitable.

The technique of discounted cash flow was employed to assess the future value of anticipated cash flows resulting from the adaptations. The rate set is said to 'discount' or reduce future cash flows to allow for the cost of capital, or in the case of the Net Present Value (NPV) method the 'discount rate' which in this project has been set at 10%. At the time the work was done in 2006 – 2008, typical borrowing costs for farmers were about 7%. However investments to reduce the impact of extreme events have the associated risk that the event may not occur for several years. It was felt that a discount rate of 10% represented what might be considered a reasonable minimum rate of return given the riskiness of the investment.

Adaptations requiring capital investment were evaluated by the calculation of Internal Rate of Return (IRR), Net Present Value (NPV) and payback period techniques. NPV is a well established technique (Turner and Taylor, 1998; Warren, 1998) that calculates the future value of an investment discounted to the present. The technique has also found favour when applied to measuring the financial effects of climate change (Anda *et al.,* 2009). IRR calculates the rate of return at which NPV is zero, in other words the actual rate of return of the investment. Because the adaptations had different time profiles and quantities of capital invested, using NPV creates problems in comparability.[1]

An assessment had to be made of the frequency with which future extreme weather events would happen as the potentially positive returns to adaptations would only occur in those years, whereas with adaptations requiring capital the costs of that capital investment would also be borne in years when the extreme event did not occur.

Some of the research evidence on adoption and diffusion of innovation leads to the diagnosis of three types of farmers with at least one type, the resigned pragmatists, unlikely to seize upon adaptations to climate change with any degree of zeal (Angell, 1997). For the purposes of this research the process leading to changes in farming systems was assessed on the basis of rational economics - that is simply the impact on profit point as the trigger for adaptation. There are potential limitations to this approach when the wider evidence of farmers' multiple objectives, such as a need for independence particularly amongst the proprietors of smaller farming businesses, are taken account of (Gasson, 1973). However the project team felt that taking a simple profit maximising approach was appropriate in the first instance, although actual farmer behaviour is clearly more complicated.

Selection of Adaptations to be included in the Detailed Costing Exercise

Seven adaptations were selected for more detailed costing. Quotas were set for the number of adaptations involving a single enterprise. Adaptations were selected on the basis of IRR. A few adaptations were rejected for more costing if they were obviously highly profitable since little more would have been learnt. A range of enterprises were represented in the selection of adaptations chosen for detailed costing on the grounds of having chosen enterprises that presented a balanced mix across agriculture in the UK. In this way no significant major enterprise was left out of the assessment. Detailed assessments were undertaken on a basis that allowed for differing regional results to show through the costing methodology, on the grounds of criteria such as climate and soil type.

Return on capital employed was the chosen measure of overall financial viability of the chosen adaptation and this was calculated on one of two bases, depending upon whether or not long term capital investments were made:

If the adaptation involved long term fixed capital investment then IRR was assessed from the Discounted Cash Flow analysis.

If there was no long term fixed capital investment but some extra working capital investment, such as additional spray treatment, then the return to this capital was assessed by a specialist.

In this way 28 adaptations were assessed using this methodology and then sampled again to provide a broad range of possible adaptations that reflected the major enterprises. A short list of nine adaptations was then selected for detailed economic assessment.

1. It has since been suggested to the authors by Philip Lund that a superior approach would be to use the test discount rate to calculate NPVs, divide the NPVs by the capital invested to get £ of NPV per £1,000 invested and rank the adaptations on this basis.

The detailed assessment took into account regional projections on the frequency of occurrence of extreme weather events which was variable for conditions such as the incidence of calf pneumonia. This was achieved by selecting representative regional cells of the Met Office Hadley Centre Regional Climate Model (HadRM 3). The variables required for each adaptation and the thresholds required to trigger an impact, and subsequently an adaptation, were defined from literature and expert opinion. Seven cases were further shortlisted and then subjected to a detailed analysis of background data, climate data and economic impact of the adaptation. Table 2 summarises the variables and thresholds used with the chosen adaptations.

RESULTS

Met Office Analysis

The analysis undertaken by the Met Office compared the occurrence of extreme events in the historic period 1961 – 90 with predictions from their regional climate change model (HadRM3) for the period 2011 – 2030. The extremes examined were for heatwave duration and timing, heatwave frequency, growing season start and end dates, frequency of frost days, duration of dry and wet periods and precipitation intensity.

The principle findings from this aspect of the project were that frost day frequency is predicted to reduce significantly in all areas and that growing season will lengthen, notably in the north of England and Scotland, supporting the findings of the above introduction (Reilly *et al*., 2007). Other findings were that heat wave duration, that is an increased occurrence of six consecutive days when the maximum daily temperature exceeds 32^{o} C within a 10 day period, will increase in the south of England.

Farmer Focus Groups

There were two rounds of farmer focus groups recruited for particular enterprises and held in Wisbech (arable & fruit), Hereford (mixed farming), Coleraine, (mixed livestock and dairy), Aberdeen (cattle and sheep), Barnstaple (mixed grazing livestock) and Malton (poultry & pigs).

The general extreme trends identified by the six focus groups were hot summers, drought, mild wet winters, extreme rainfall, early and late frosts and hail and strong winds. The groups reported their experience of a wide range of weather impacts. For example, the costs of crop drying and loss of outputs such as reduced milk production in hot weather. For the effects of frost and hail the groups' experiences were of yield reductions in arable and horticultural operations, repeat drilling owing to crop failure, a reduced effectiveness of fungicides and an increase in expenditure disposing of slurry/ manure with a reduction in trafficable days in winter.

Changing weather patterns were well recognised by all farmers but did not yet appear to be at a frequency required for farmers to make significant change. To bring about such change extreme weather resulting in yield loss would be necessary in two consecutive years. This potential adaptive response was grounded within the framework of the financial climate facing farmers at

Table 2 – Seven adaptations costed in detail - Summary of the variables and thresholds used to derive the frequency analysis.

Sector	Extreme	Adaptation	Description including Variables and Thresholds
Poultry	Frequency/timing of heat waves; Frequency of extreme heat	Housing redesign - improved permanent ventilation	The poultry crop is affected by heat most during days 30-42 of the crop cycle when the birds are nearly fully grown and space within the poultry house is at a premium. These periods are typically during the summer. More than one crop can be impacted by a heat wave or extreme heat period with losses occurring not only to due to more intense heat but potentially because there are more of them in a year. The analysis defined critical hot days by findings spells of 2 days or more where the Tmax > 30 °C. It was assumed that given the number of operations in any region that at any one time there would be an operation with a flock at the required growth stage. An optimized routine searched all subsequent day 30-42 periods allowing a 7 day window between crops to define the maximum number of crops in a year that may be impacted by heat.
Beef & Sheep	Frequency/timing of heat waves; Frequency/ duration of dry spells	Storage reservoirs/ Water capture	The lack of natural water in streams requiring the provision of water for stock is difficult to model simplistically and using more sophisticated models was beyond the scope of the project. The analysis defined dry days as days on which the available soil moisture was below 10 mm and precipitation was below 1 mm. The number of dry days between July and October were totalled and years where more than 30 such days occurred defined as years in which natural water would be difficult to access.
Arable - Root crops	Frequency/timing of heat waves; Frequency/ duration of dry spells	Irrigation- potatoes	Running a sophisticated water budgeting/irrigation scheduling model like Irriguide for each region was beyond the scope of the project. However, using experience gained from developing/using this model and drawing on 20 years of potato irrigation trial data from the ADAS Gleadthorpe Farm the following parameters were defined. Years in which irrigation would not be sufficient were years in which the soil moisture at the start of the growing season (mm) + precipitation (mm) + 150 mm of irrigation water < 375 mm.
Horticulture - Soft fruit	Frequency/timing of heat waves; Frequency of extreme heat	Investment in cooling and transport temperature control	Soft fruit spoilage is a function of fruit temperature which is affected by maximum temperatures during the daytime and ambient air temperature at night. Days on which this spoilage would take place were defined as days where TMax > 30°C and TMin > 15°C. Years with one or more of these days were determined as well as the average number of spoilage days per year.

Sector	Extreme	Adaptation	Description including Variables and Thresholds
Arable - Cereals	Growing season length; Frequency/timing of frost	Spread risk - grow range of varieties with different flowering dates	Frost days were defined as days where TMin < 0°C during the flowering period, namely, May/June. The number of years in which this would potentially be a problem was determined.
Beef & Dairy	Frequency/timing of heat waves; Frequency/timing of frost	Housing redesign - improved permanent ventilation	The incidence of Enzootic Calf Pneumonia (ECP) in cattle is difficult to model as there are three suites of causative factors with many of these poorly understood, namely etiological agents which include a range of viruses, calf factors which include nutrition and age and environmental factors. This model focuses on the environmental factors as these are the factors addressed within the adaptation. Potential ECP periods were defined as days where TAve > 10°C, RH > 90% and wind speed is < 6.5 km/hr for 3 or more days during the period October to February. Years with one or more of these periods were defined as years in which pneumonia was likely.
Sheep	Frequency/timing of heat waves; Frequency/ duration of wet spells	Increased dipping	The flystrike season length was determined as the first and last five day period where TAve > 8.5°C. Within these seasons the flystrike days were defined for 3 different periods, namely pre-shearing, post-shearing when fleece in adults and lambs is growing and late season when it is fully grown. The fleece length affects the fleece humidity as well as the amount of rainfall required to get the fleece wet. Using the model described by Wall *et al*. (2002) the following parameters were defined: Pre-shearing (until 18 June): TAve > 8.5°C and Precip or Precip + fleece moisture (mm) > 5 mm Post-shearing 1 (19 June till 30 September): TAve > 8.5°C and Precip or Precip + fleece moisture (mm) > 15 mm Post-shearing 2 (30 September till end of season): TAve > 8.5°C and Precip or Precip + fleece moisture (mm) > 5 mm

the time of the focus groups early in 2006. It was felt that such changes would only be seen to be worthwhile if the financial outcomes could be seen to be satisfactory at the time the assessment was made.

Inevitably there was spatial variability in some of the responses to the focus group questions, for example the Northern Irish and Scottish focus group participants did not feel that extreme heat would ever be a problem for them. Many low cost adaptations were already being used by some, such as putting stock in fields with good shade, whilst potentially this might cause another issue in this case as shade for sheep can give rise to fly problems and additional disease. There was agreement that the provision of accurate long range weather forecasts would assist farmers in making the necessary decisions at farm level.

ADAS Farmers' Voice Survey

To draw on a wider body of farmer experience than the members of the farmer focus groups, questions about climate change were included in this large postal self completion survey which has been carried out regularly by ADAS in England and Wales since 1999. Questions were included in the 2005, 2006 and 2007 surveys (1,200, 2,100 and 2,000 respondents respectively). The 2005 survey highlighted that the vast majority of the sample respondents had either not responded to extreme weather (43% in England and 33% in Wales) or had not experienced it (38% in England and 50% in Wales). Some 16% of farmers had made an adaptation to extreme weather. Larger farms showed a slightly greater tendency to adapt than smaller ones and those in the North West region gave the highest positive response at 25%. The proportion of respondents to the 2006 survey intending to react constructively to climate change within five years increased to 46% in England.

Respondents were asked to indicate likely changes to be made and these are shown in Table 3 below.

The average number of changes to be undertaken per holding was 1.9 in England and 1.8 in Wales. Increasing off-farm income or getting out of farming altogether were popular adaptations in both England (41%, and 16% respectively) and Wales (30%, and 12% respectively). However, such behaviour is unlikely to be driven by solely extreme weather patterns. Large farms in England showed a greater tendency towards investment-based responses such as irrigation and livestock housing.

On the matter of the impact of climate change on business performance the 2005 survey found that 71% of respondents took the view that there would be a neutral impact on business performance, or they were unsure what the impact would be. Only 6% of respondents in England and 4% of respondents in Wales felt they were well informed on the issue of climate change. Types of extreme weather that did cause concern were drier summers, wetter winters, intense rainfall and extremely high temperatures, although these results varied with farming sector and region. The horticultural sector was particularly concerned about intense rainfall, unseasonal frost and vagaries in the start and finish of the growing season.

Some linkage between higher levels of concern and adaptive behaviour is

Table 3- Adaptations intended as a result of climate change by region in 2006

Adaptation	North East	North West	Yorks & Hum-ber	East Mids	West Mids	East-ern	Sout h East	South West	Wale s
Replace existing crops/livestock with new varieties	30%	11%	29%	23%	10%	36%	27%	24%	7%
Introduce new types of crops/livestock alongside those cur-rently grown/kept	24%	13%	31%	23%	34%	32%	27%	27%	12%
Increase off farm income sources	46%	31%	44%	51%	40%	50%	36%	40%	30%
Invest in irrigation	4%	8%	2%	3%	5%	12%	17%	1%	3%
Invest in livestock housing	9%	24%	9%	9%	15%	5%	13%	18%	29%
House livestock ear-lier/later in the year	27%	37%	12%	15%	25%	6%	20%	32%	39%
Change timing of sowing/spraying/ fertiliser application	37%	36%	45%	37%	31%	51%	37%	37%	3%
Cut down on stock	0%	18%	0%	11%	0%	5%	3%	0%	12%
Continuous review/ will respond as Required	14%	18%	20%	38%	7%	0%	22%	17%	9%
Energy (bio-crops/ hydro/wind power etc)	0%	4%	36%	11%	8%	30%	0%	14%	0%
Will retire/sell up/ emigrate	18%	18%	17%	0%	23%	30%	10%	15%	12%
Will stop main stream farming/ diversify (unspec)	0%	25%	0%	0%	3%	0%	0%	0%	0%
Reduce energy use	0%	6%	12%	16%	0%	0%	5%	0%	0%
Plant woodland	0%	10%	0%	0%	31%	0%	0%	5%	0%
Change heating (new heaters/lower tem-peratures)	0%	0%	0%	0%	0%	0%	0%	18%	0%
Convert to organic	0%	0%	0%	0%	0%	0%	0%	3%	0%
Let out/lease land	0%	0%	0%	0%	0%	0%	0%	0%	24%
Livestock will stay outside	14%	0%	0%	0%	0%	0%	0%	9%	0%

evident with such behaviour running at between 9 and 14% for the areas of climate change showing greatest concern. Indeed 71% did not indicate that they were adapting to any of the conditions shown. Whilst there appeared to be concern amongst farmers it was a matter for the future rather than the present, although this might be interpreted as a result of not being well informed on the matter. The level of adaptive behaviour was certainly linked to the farming sector represented, for example the pig and poultry sector consistently showed a very low level of interest in adaptive behaviour. The anomaly was that indoor poultry producers contributing to the focus group sessions and pig producers known in the industry had demonstrated some enthusiasm for adaptations in response to climate change. In the livestock sector the adaptations to climate extremes involved a combination of some system change and investment in some additional inputs and production facilities. The welfare of livestock being transported can be adversely affected in very hot weather and attention to the ventilation system coupled with reducing stocking density in transit is the positive adaptation. The environmental consequences of adaptations to heat extremes are generally neutral; however there is a significant positive impact on animal welfare.

Costing of Adaptations

The 28 costed adaptations for each extreme included the forecast of the impact on profit and an investment appraisal and a summary table was produced with a description of the event, enterprise impact and description of the adaptation.

Table 4- Summary of Water Storage - capture

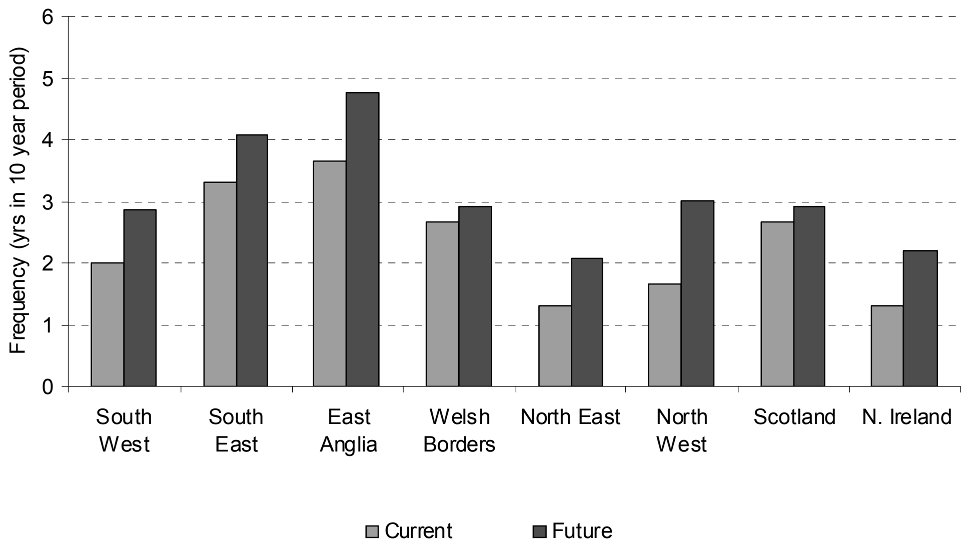
Extreme event	Frequency/timing of heat waves; Frequency/duration of dry spells	Frequency/timing of heat waves; Frequency/duration of dry spells
Adaptation	Irrigation in Top Fruit	Irrigation in Top Fruit
Impact of Extreme	Drought would affect yields and quality of fruit. It would also lead to poor tree growth and affect future years production.	Drought would affect yields and quality of fruit. It would also lead to poor tree growth and affect future years production.
Description of adaptation	Install irrigation system and progressively replace with more drought tolerant varieties.	Install irrigation system and progressively replace with more drought tolerant varieties.
Extreme frequency	2 in 10 years.	
Capital invested	£18,200	
Effect on profit	+£3,159	
NPV	£28,391	
IRR	33%	
Break even frequency	1.1 events in 10 years	1.1 events in 10 years

An example of this is shown below for the irrigation of top fruit. Top fruit yields would be reduced with the occurrence of 14 days without rain combined with temperatures of greater than 32°C. The scenario allows for a 14 hectare apple orchard and the installation of a sprinkler system to apply 25 mm of water per week during spells of high temperature. Table 4 summarises the data and financial outcomes of the adaptation.

One of the seven adaptations costed in depth was improving ventilation by installing electric fans in calf rearing buildings to reduce calf deaths from pneumonia. The cost of pneumonia to cattle farmers is estimated to be about £80 million per year for the UK and includes the cost of treatment, reduced growth, additional work and most significantly, calf deaths. The micro-organisms that cause the disease are found in nearly all cattle herds but pneumonia is only a problem on some farms as a result of the environment and management. There are many factors predisposing calves to pneumonia but a very important one is ventilation. Cold, humid conditions, sudden changes in air temperature and stress due to changes in the environment are associated with pneumonia outbreaks in young calves. This scenario assumes that vaccination is part of current farm practice.

Humid calm heat waves in winter are periods when calf pneumonia may be triggered. These currently occur 2.33 times in a ten year period but by 2020 are predicted to occur 3.1 times in a ten year period.

Figure 3: Frequency of humid, calm winters heat waves, by region (for cattle pneumonia)



The economic impact of spending £4,000 to invest in electric fans in an existing calf rearing building is shown below. Improving the ventilation is assumed to reduce mortality from 8% to 4%.

Table 5. Summary of economic impact of investing £4 000 in electric fans to improve the ventilation in a calf rearing building.

	Effect on Profit £			IRR%		NPV£	
	Current	Future	Change	Current	Future	Current	Current
	£	£	£	%	%	£	£
N. Ireland	-156	989	1145		27	222	5319
Scotland	344	433	89	18	19	2447	2845
North East	-156	120	276		15	222	1451
East Anglia	717	1130	414	23	29	4170	5950
Welsh Borders	344	433	89	18	19	2447	2845
South East	590	866	276	22	25	3543	4771
South West	94	414	321	14	19	1335	2762
North West	-29	474	503		20	787	3028

In three parts of the UK (N. Ireland, the North East and North West) it is not currently worth making the investment but by 2020, due to the increased frequency of these weather events the investment becomes worthwhile.

DISCUSSION

The ability to separate out the effects/impacts of general climate change and climate variability from the impacts of climate extremes has been a distinct difficulty in the more qualitative parts of this project. The impacts from general climate change trends are often amplified within the extremes. Similarly, it has been necessary to disentangle the synergistic and knock on effects of the various extremes with many of them happening at the same time. As an example, increased dry spell duration is usually associated with elevated temperatures and heat waves leading to water resource issues. It has also been necessary to consider the antagonistic effects of the extremes where the benefit of one is negated by another as exemplified by the extended growing season. This may bring opportunities to crop earlier to avoid the mid-summer drought or even the potential for additional cropping. However, earlier cropping can make certain crops particularly vulnerable to late frosts, be offset by an increase in the length of the mid-summer drought or be negated by shorter, wetter autumns. The timing of this synergism/antagonism is often key to whether these combinations are considered detrimental or beneficial and are often sector specific. An example is the synergism of dry and warm conditions -in spring when soil moisture is not a limiting factor to grass growth these conditions are favourable for the sheep sector, however, in the late summer these conditions produce difficult harvesting conditions for the root crop portion of the arable sector.

There is renewed determination internationally to deal with the effects of GHG and global warming (Harris, 2009). This places the subject of the response of the farming industry to these matters further up the farm business agenda. This study has gauged the opinion of a representative sample of farmers drawn from the agricultural industry on how well informed it feels with respect to climate extremes, its experiences of climate extremes, what if anything it has already done to adapt and what if anything it would consider doing to adapt. Most farmers in England and Wales do not feel well informed and farmers that consider themselves to be better informed are more likely to have responded already or to intend to respond over the next 5 years. This highlights as a minimum information dissemination as a key priority. Most farmers have experienced extremes and in some instances have chosen to adapt, while many accept that loss as a result of climate variability is an inherent part of farming. The projections indicate increased frequency and intensity of extremes in the future, even by 2020. Despite this, most farmers state that they are unlikely to adapt in advance of experiencing the changes for themselves with the major drivers for adaptation being current economics and regulation. There is a perception of a need for government action by some researchers in calling for 'a clear strategy of land management' (Taylor, 2008). If enacted this would clearly have an impact on farm business management.

Of all the climate extremes that are predicted, the effects of temperatures and/or low rainfall are considered by all as the aspect of change of greatest concern to the industry. All but one of the climate extremes has a negative effect on the farming system. The potential exception is an opportunity to increase production by including additional crops. However, in the context of climate extremes, additional cropping does not feature well. The climate extreme is, as suggested by the title, an untypical or unexpected event. This differs from climate change which should over time offer greater reliability and potential for adaptive behaviour (Reilly *et al*. 2007).

Perhaps the closest to this is the potential for additional cropping as a result of an extended growing season. Currently this is a technically feasible option for some producers, but not a reliably economic option. The forecasts suggest that the potential will increase with increased frequency of a longer growing season. If greater reliability of production could be achieved, and the supply chain, especially the retailers, could accept UK produce instead of importing potentially lower cost produce, there may be scope to develop this further. Recent developments in the international money markets could affect this balance with the considerable decline in the value of Sterling against many countries that supply our food imports providing an opportunity for production here. The difficulty is that the scenario currently has too many 'ifs and buts' coupled with the retail chains aversion to risk in the context of reliability of supply.

When considering alternative adaptations it is considered vital that the adaptation in no way compromises the relationship between producers and the market place. The quality of the product has to be maintained. In this context quality comprises the whole range of requirements of the process and retail supply chain, from the eating quality to the volume, seasonality and availability of the produce. Within the context of adaptation to climate extremes, the project has not identified potential adaptations that would add value to the produce, or target a niche market. If such adaptations could be identified for other commodities and markets then the financial returns available may encourage producers to consider system changes.

Climate extremes place a greater burden on the livestock sector than arable and horticultural sectors due to the combination of financial and animal welfare effects. Plants do not have any welfare rights and thus financial considerations can dominate decision making. With livestock the white meat sector has greatest exposure to welfare pressures over finance due to the combination of numbers of livestock in a typical enterprise and the modest margin per unit of livestock constraining the opportunity to profit from investment in adaptation. The financial returns from an adaptation may not be sufficient to justify the investment and the response is to accept the loss whenever the climatic extreme occurs.

Welfare requirements place a greater onus on farmers to adapt their production systems. The speed of onset of events also requires livestock producers to seriously consider anticipating adaptation such as investment to militate against extreme heat events. The industry suggestion is, however, that even in situations in which an extreme would compromise the welfare of livestock, producers may well have to experience the impact of an extreme before making an adaptation. Producers generally appear to feel poorly informed about climate change impacts such as extreme events. This finding might change if there was better communication with farmers about climate change. However, given the strategic nature of decisions to be made, the response of the individual farmer will depend, as ever, upon the wider personal and business objectives and not solely on the immediate impact on businesses that the extreme event could cause.

The study has budgeted adaptations to production systems well beyond the normal planning window for most farm businesses as many farms plan one or two years ahead, although some arable units may plan a little further ahead than this. Changes will be brought about by the prospect of changes in the business environment and how this impacts on other existing or potential enterprises. This study has shown that adaptation to climate extremes is currently a low priority amongst farmers who are reacting to shorter timescale pressures that dominate their decision making framework. The last two years have seen wide gyrations in both fuel and fertiliser prices, both of which on most farms are important financial and physical inputs.

The adaptations identified for the climate extremes affecting the arable sector can largely be achieved through changes in working practices, combined with some modest expenditure on pesticides for the control of weeds and slugs, meaning that for most arable enterprises there is no requirement for large capital investment or the need to significantly change the mix of enterprises. The arable sector adaptations to climate extremes do have some positive and negative consequences for the environment. Crops requiring irrigation will have the need met from the positive effect of winter abstraction and storage rather than the negative effect of abstraction during the growing season. However, negative environmental effects can arise from the creation of the storage reservoir and the increased use of fuel to pump water.

Although in the main the adaptations to horticultural enterprises involve greater levels of innovation than in arable or livestock sectors, the generally higher value per unit of outputs has provided greater scope for the adoption of novel and innovative approaches. In the cropping domain it was two arable adaptations that involved potatoes which were again higher value outputs. The three livestock adaptations given detailed analysis dealt with ventilation for poultry in conditions of heat stress, insulation of pig arcs against excessive heat and water harvesting. In these latter cases the driver was as much improved animal welfare as much as the value of the product and the financial return achieved. Welfare requirements place a greater onus on livestock farmers to adapt their production systems and the speed with which these events can occur suggests that early consideration of adaptations would be desirable. Unfortunately this may prove difficult given the low level of readiness to adapt before extreme events are experienced.

Stocking density is also an issue for the management of housed pigs and poultry during heat extremes and action to reduce densities needs to be taken well ahead of such extremes. It would be very inefficient if farmers kept space available and vacant in the event of a weather extreme event. More 'welfare friendly' production systems operated with a retail incentive have reduced stocking density on some farms, but it is too early to say how large a proportion of production might develop in this way, however this adjustment will certainly help to reduce the susceptibility to weather extremes on those farms that have exploited this opportunity.

A further issue for livestock producers is the storage and handling of manure and dirty water on livestock farms. The requirements for Nitrate Vulnerable Zones (NVZs) have resulted in the need for increased storage facilities. Although effluent tanks are sufficient to meet the needs of current regulatory requirements they would be unlikely to provide adequate storage facilities in an intense rainfall extreme.

There is also the wider issue to be considered of the long term efficient and competitive production of food and food security in the UK after the 2020s. The time scale of this project is far too short to consider matters such as the location and potential relocation of food production to avoid an extreme. For example, relocating poultry production to regions that might avoid high temperature extremes could have an effect on the location of the processing capacity and transportation of the poultry themselves.

CONCLUSIONS

The objectives of the study were to identify and budget for the effects of climate change and extreme weather events on agriculture in the UK through to 2020. The outcomes were that agriculture is neither well prepared nor well informed about anticipated changes in extreme weather events at a time when the subject has moved near to the top of the world agenda. Where farmers have adapted or are planning to do so they have done so autonomously and in response to their experience of extreme seasons rather than with the view to adapting their businesses in order to compete in a changed natural environment or purely motivated by profit. The economic costing exercises undertaken in this study were of potential farm level adaptations rather than those that might be undertaken at industry level for such inputs as the development of new plant varieties.

Extreme events, their impacts and adaptation to them have been particularly difficult to forecast. However, what is clear is that extreme heat, increasing dry spell duration and their combined impact on water resources seemed to be of particular concern to the agricultural industry. This is manifested for the livestock sector as potentially extra costs to maintain acceptable conditions of animal welfare whilst with other sectors, notably those with higher value crops such horticulture and potatoes, there might be some possibility for higher returns. The level of awareness of climate extremes was found to be low and variable, as were the levels of existing adaptation. This suggests that readily available and easily digestible information sources, possibly to include a database of options of what has been tried and tested, would be a particularly useful resource.

The environmental consequence of adaptation was generally the input of additional resources of various kinds. Increased variable inputs including such items as pesticides, fertiliser and water whilst other resources might be labour, power or machinery and capital might be consumed in improved facilities and equipment. Whilst the increased consumption of some of these resources does not dictate a negative environmental impact there is more scope for this arising.

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