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THE VOICE OF BREWERS & PUBS

ZERO CARBON FORUM

UK Brewing Sector: Climate risk and resilience

April 2025

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UK'S LEADING MANAGEMENT CONSULTANTS 2019 – 2025

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Widespread rising climate risks set to tighten long-term malting barley supply

Eastern England faces growing climate risks

UK's east coast, which supplies over 65% of malting barley for brewing, is vulnerable to climate change impacts. By 2040, summer rainfall in the key growing regions is projected to decrease by 2.2 - 7%, while temperatures will rise by 1.5 - 1.75C from a 1986 - 2006 baseline, **increasing drought and heat stress**. Autumns will also become wetter, heightening risks of waterlogging and soil-borne diseases like Fusarium.

Uncertainty in long-term international barley supply

European barley-growing regions, particularly in **Southern Europe**, are already experiencing **drought, extreme heat, and flooding**. Research suggests that under high warming scenarios, global barley supply could drop by 15%, with the **share allocated to beer production decreasing by 20%**, as food and livestock feed take priority.

Barley market volatility may threaten UK brewing sector

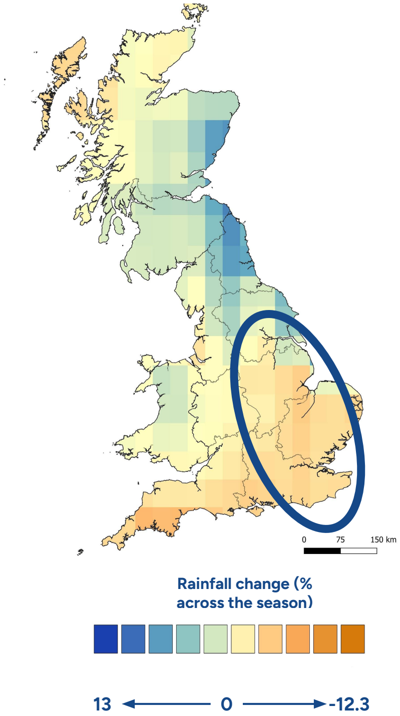
Increasing extreme weather and associated geopolitical instability will drive malting barley price volatility for UK brewers due to the **global nature of cereal markets** - as seen for example in 2018, when European droughts led to a ~30% increase in malting barley prices.

Urgent need for adaptation and resilience measures in UK

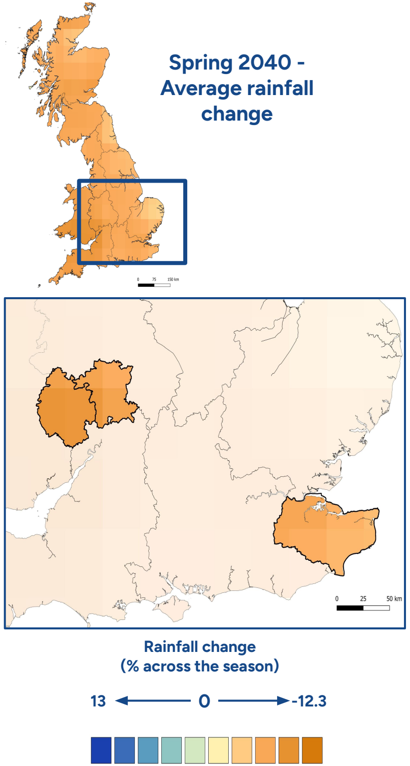
UK agricultural **land use may shift away from brewing, prioritising animal feed and direct food production**. A UK study found malt barley deficits by 2050 under various climate, land use, and population growth scenarios. Without certain overseas supply alternative, the UK brewing sector must urgently implement adaptation measures to safeguard future malting barley availability.

2040 summer - Rainfall change

Key indicator of drought



Concentrated hop-growing locations and varieties poses significant risk of yield and price impacts



Moderate risks of drought and acute flooding events in UK

UK hop production, now concentrated in Kent and Herefordshire, faces increasing risks levels under a 2.8°C warming scenario (RCP 6.0). Average spring rainfall is expected to decline by 7 - 12% by 2040, **affecting the water-intensive growth period** for hops. Additionally, increasing areas surrounding mature rivers in each region will be at risk from acute flooding events.

Key international hop-growing regions face severe risks

The UK brewing sector heavily **relies on imports from the US (Pacific Northwest) and Germany**, both of which are at risk of experiencing severe drought and extreme temperatures. While irrigation has mitigated some drought effects in the US, this cannot be relied upon as a long-term solution. Worsening conditions threaten both yield and flavor quality.

Specificity of hop varieties poses challenges to sourcing shifts

The sensitivity of hop flavor profiles and inability to easily change recipe formulation restricts brewer's ability to diversify sourcing in the short-term. However, intensifying impacts from climate risks in concentrated hop-growing regions may cause **shortages and price spikes for key varieties**. UK brewers should therefore be prepared to adjust product portfolios in the long-term.

Potential to expand UK hop production with proper adaptation

As overseas hop-growing areas may become less viable, the UK could see relatively more suitable growing conditions in the coming decades. However, **scaling up domestic hop production will require risk mitigation measures**, such as targeted breeding programs, to ensure resilience and meet flavor profile requirements.

Targeted adaptation measures can build agricultural supply chain resilience

Given the increasingly severe climate pressures on barley and hop production, targeted adaptation interventions at the farm level are essential for ensuring long-term resilience of supply for brewers.

The 10 priority agronomic measures shown in figure 0.1 have been identified as effective for mitigating material risks. A structured evaluation of each measure's co-benefits and relative cost scale resulted in the groupings below:

- **High-Impact, low-cost measure with strong co-benefits:** cover cropping, composting & reduced tillage, IPM & species diversity
- **Medium-cost measures with strategic importance:** precision irrigation, rainwater harvesting, precision agriculture & monitoring
- **Higher-cost, challenging measures requiring long-term investment and enablers:** cultivation of drought & heat-tolerant varieties, and drainage infrastructure

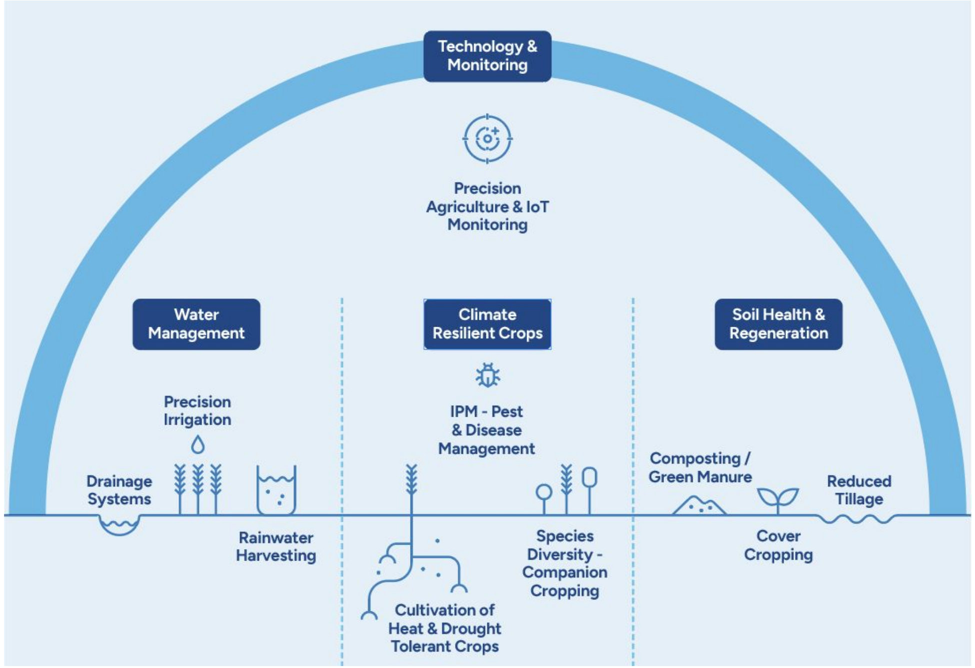


Figure 0.1: *10 priority agronomic measures that farmers can implement to mitigate material risks. Source:3Keel*

Urgent collective brewing sector action is required to secure supply for the long term

UK brewers must take joint action to tackle climate risks to their supply chain. Seven practical recommendations are outlined in Figure 0.2.

They are designed taking a sector-wide perspective, with recognition that driving change upstream, on farm relies upon a unified approach across UK brewers. Various concrete underpinning actions are provided for each recommendation, along with an assessment of effort level required.

Recognising the critical role of government support in sustainable adaptation, we have also highlighted six key policy enablers for action.

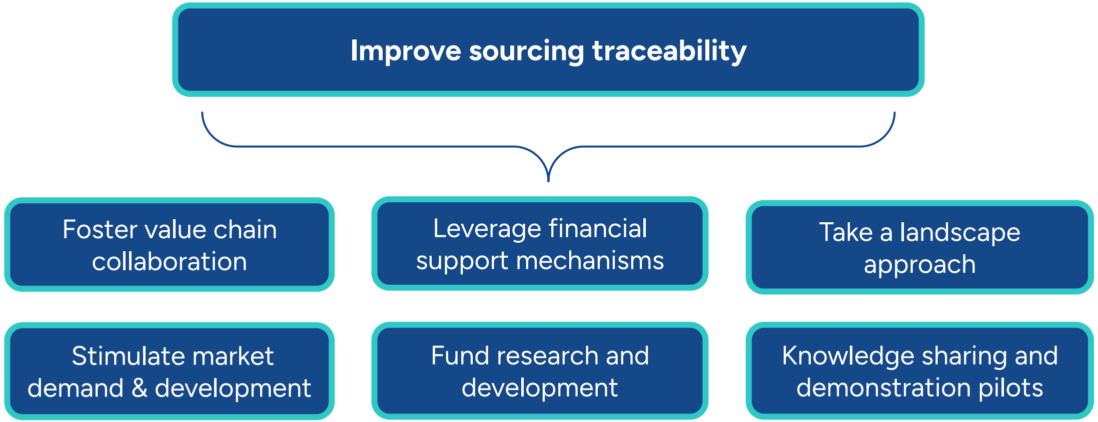


Figure 0.2: *7 practical recommendations for UK brewers to tackle climate risk. Source: 3Keel*

01. Introduction

Project context and aims

As the impacts of a changing climate hit agricultural supply chains, it is clear that the UK brewing industry is vulnerable to risks can which ripple from farm to pint glass.

Acknowledging these risks, in 2024 the British Beer and Pub Association and the Zero Carbon Forum commissioned specialist sustainability consultancy, 3Keel, to carry out a project to assess climate risks facing the UK brewing sector and to identify actions to build resilience. The assessment focuses raw material input risks, as these were deemed as most existential, with the potential to disrupt the sector’s ability to operate.

The primary target audience of this study are UK brewing companies. However, its findings are relevant for a range of other stakeholders including farmers, crop traders, hospitality customers and policymakers.

Recognising that many individual UK brewers have carried out their own risks assessment, the purpose of this project is to raise collective awareness, with an evaluation at a sector level, to provide transparency and a common ground for joined up action.

Project aims:

1. To assess **expected severity and potential impact** of most material physical supply chain risks to the brewing sector
2. To identify **effective adaptation interventions to build resilience against identified risks**
3. To assess the **expected wider impacts** of identified risk adaptation interventions on GHG emissions, water and biodiversity
4. To **develop clear recommendations** for the brewing sector on priority actions to mitigate climate risks and build resilience

INTRODUCTION

UK brewing sector sourcing profile

Malting barley used by UK brewers almost exclusively grown domestically

The vast majority of Malting barley sourced by the UK brewing sector is grown domestically. barley **imports are relatively minimal**, in 2023 they totalled ~135,000 tonnes (less than 2% of volume produced in the UK), all grown in the EU.[1]

Barley is the second most produced crop in the UK, after wheat, and the UK is among the top ten producers in the world. In the UK, about 60% of total barley produced is used for animal feed, **~30% is used for Malting (both brewing and distilling)**, while the remaining goes into minor uses such as seed, stock, food or waste.[2]

In 2023, approximately 6.9 million tonnes of barley were produced in the UK in total. Production is regionally dispersed, but there is a particular concentration of growers in Scotland (where most barley is used as a distilling input) and on the English East coast.

The UK's Malting barley supply consists of **both winter and spring barley varieties**, each with distinct brewing and agronomic characteristics. Spring barley is increasingly popular due to its lower protein content, and higher extract yield, whereas Winter barley is in some ways more climate-resilient and higher yielding, but its higher protein content and lower enzyme activity can make it more susceptible to needing to be blended.

Region	Approx % of UK barley for brewing*
Eastern	24.18
East Mids	14.78
Yorkshire & the Humber	12.44
South East	12.32
South West	11.14
North Scotland	8.25
South Scotland	7.47
West Mids & Wales	4.59
North West	2.51
North East	2.33
Total	**100**

Table 1: *Source: [3] - adapted based on assumption of 90% of Scottish grown barley used in distilling, rather than brewing.*
**Calculated using an assumption of 30% malting: 60% animal feed split for barley across all UK regions*

Steep decline of UK domestic hop growing in recent decades

The **UK hop sector** has deep historical roots, once a powerhouse in the 19th century with nearly 3,000 growers farming 77,000 acres across regions like Kent, Herefordshire, and Worcestershire.

Competition from imported hops, changes in consumer taste, and the rise of lager reduced UK hop farming to just 2,000 acres managed by 45-50 growers today, **meaning ~90% of the hops used to brew beer in the UK are now imported from overseas.**[4]

Despite this decline, British hops are vital to the **UK brewing industry**, providing essential bitterness, unique aromas, and flavors that define traditional British beers.

UK-grown hops are **experiencing a slight revival in recent years**, driven by the craft beer movement, which values unique, locally sourced ingredients.

English hop production since 2008

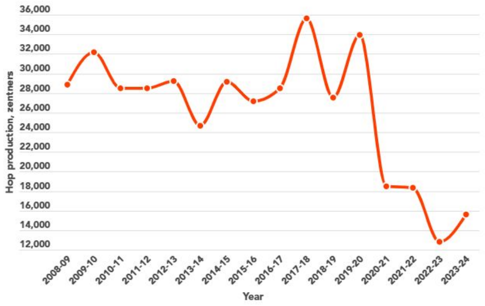


Figure 1: *Graph showing English hop production since 2008. Source:* [5]

Main UK hop growing regions

UK brewers reliant on hop production in Central Europe and the US Pacific Northwest

The UK brewing sector relies heavily on supply from major international hop growing regions. The global hop industry is predominantly led by the United States and Germany, which together account for approximately 73% of the world's hop acreage.

In 2023, **the United Kingdom imported £38.5M in hops, becoming the 5th largest importer in the world**. The value of hops imported into the UK from the United States was (£20M), Germany (£7.7M), Canada (£3M) Australia (£2.5M), & New Zealand (£1.3M). [6]

United States: The U.S. has been a major player in hop production, with significant cultivation in the **Pacific Northwest, particularly in Washington's Yakima Valley**. However, recent years have seen a decline in hop acreage. In 2023, U.S. hop cultivation decreased by 11,000 acres, bringing the total to 44,000 acres. US hops are particularly important in some modern beer styles like IPAs and Pale Ales, which require intense citrus, pine, and tropical fruit flavors that UK-grown hops do not always provide.

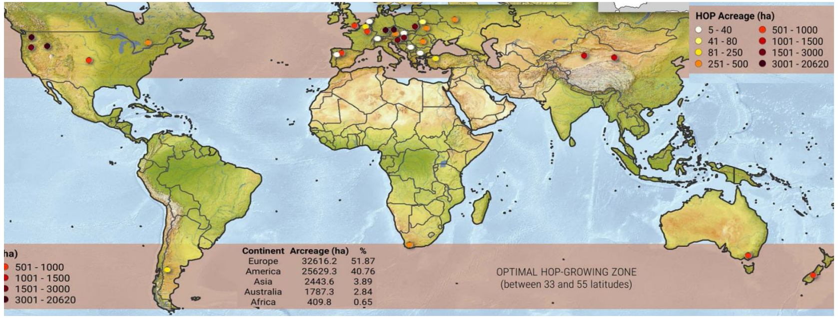


Figure 2: *Estimated hop acreage in individual countries and the approximate position of the optimal hop-growing zone. Source:* [7]

Germany: Germany has **reclaimed its position as the world's top hop producer**. Despite a slight reduction in hop cultivation area by 840 acres, Germany's total stands at c. 50,000 acres in 2023. German hops, particularly high-alpha varieties, are a cost-effective way to provide bitterness in beer. Varieties like Hallertau Magnum and Taurus offer high alpha acid content, meaning less hop material is needed per batch, reducing brewing costs.

02. Risk and impact assessment

Climate scenario modelling and risk: projections, not predictions

This study includes a detailed assessment of the potential scale of **three physical climate risks on barley and hop growing in the UK**. We used GIS mapping to identify the UK regions where the manifestation of risks is projected to be most severe. Accounting for the unique vulnerability of hops and barley to each risk allowed us to identify location-specific hotspots per crop.

From desk-based research, we also assessed the magnitude of **material climate risks in key international hops and barley sourcing locations**. We drew on secondary risk modelling studies and agronomic experiments as an evidence base.

It is important to underscore the **inherent uncertainty and complexity** in climate scenario and risk modelling. Warming scenarios such as the IPCC's Representative Concentration Pathways (RCPs) can struggle to account for tipping points, feedback loops and dynamic impacts such as societal or geopolitical shocks. While these models are valuable for understanding risks and guiding action, they should therefore be interpreted with caution and not as precise forecasts of the future.

The brewing sector's focus should be on **building overall systemic resilience to climate risks** in the agricultural supply chain, to remain prepared for a variety of potential outcomes. To enhance preparedness, risk assessments should be updated periodically to ensure strategies remain adaptive and aligned with the latest scientific developments and emerging threats.

Increasing average temperatures lead to greater extremes

The UK risk mapping exercise which follows outlines projected *average* changes in temperature and rainfall across key sourcing regions under an RCP6.0 scenario, in which temperatures are expected to increase by ~2.8C by 2100 from pre industrial levels.

There is a well-established **link between average climatic changes and the increasing frequency and intensity of extreme weather** events, including heatwaves, heavier rainfall and stronger storms. For example, the IPCC ([8]) indicates that:

- For each 1°C rise in temperature, the intensity of heavy precipitation events increases by ~7%
- With a 2°C rise in global temperatures, droughts that previously occurred once every ten years are projected to occur 2.4 times more frequently. This increases 4.1 times at 4°C
- At 2°C of warming, heatwaves are expected to happen approximately 5.6 times more frequently, and at 4°C, this rises to 9.4 times. The intensity of these heat waves is projected to rise by 2.6°C at 2°C warming, and 5.1°C at 4°C warming

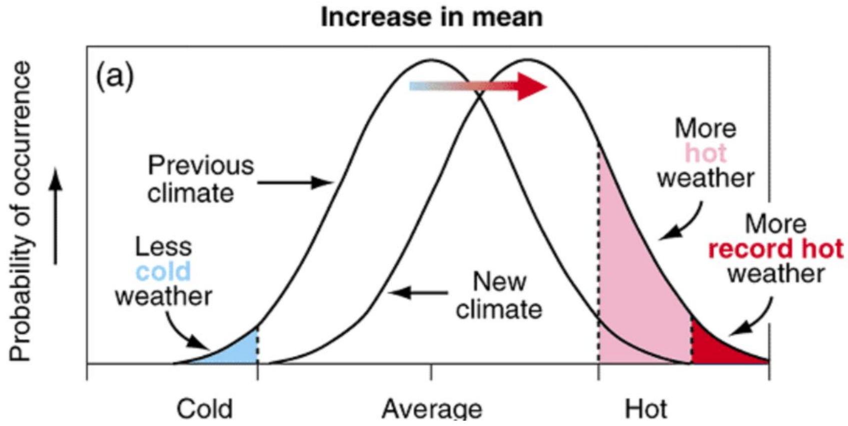


Figure 3: *Graph showing the effect of increasing average temperatures on climate extremes. Source: [9]; [10]; [11]*

RISK & IMPACT ASSESSMENT

UK sourcing risk assessment

Methodology underlying the UK risk assessment

The first activity within the sourcing risk assessment was to assess the UK's exposure to three relevant climate-related risks via a GIS mapping exercise.

The three climate hazards (risks) expected to be most material to barley and hops were identified as:

1. Mean temperature change
2. Drought - measured by rainfall change
3. Flooding

Once risks were identified, assessment parameters were defined including climate scenario and time horizons. These are summarised below

- Time periods: 2040 and 2080
- Climate scenario: RCP 6.0, which projects ~2.8C of warming by 2100.
- Frequency: Seasonal - identified as being particularly important for temperature and drought

The data was mapped using open source data in QGIS to produce 18 UK maps in total, the full portfolio can be found in the annex.

Visual results of the mapping show projected average trends, however, as noted on page 17, these trends will drive more frequent and intense extreme weather events. Our commentary in the following section reflects this.

Projected increasing incidence of hotter and drier summers in key English barley growing regions

65+% of annual barley inputs to the UK brewing sector are produced in 4 regions on the east coast of England (circled). [3]

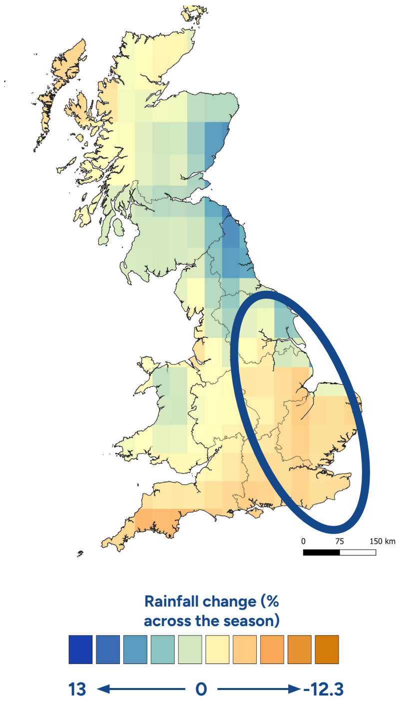
The Eastern and South East regions are already experiencing increased instances of drought and are projected to face rainfall reductions of between 2.2 - 7.2% during summer by 2040. **Drought during the Spring barley grain-filling period** (typically May - July) can lead to incomplete kernel development, lower starch content, and higher protein levels, all of which **degrade malting quality**. [12] Additionally, dry conditions in Spring create weaker root structures in barley, limiting the plant's structural integrity and nutrient flow, ultimately affecting yield.

Drought impacts are set to be **exacerbated by higher average summer temperatures in the region**, which under the RCP 6.0 scenario are projected to rise by 1.5 - 1.75C from a 1986 - 2006 baseline in the three highlighted Eastern regions.

Given malting barley's vulnerability to temperatures above ~30°C+ when flowering and grain filling, exposure to extreme heat in summer may have particularly detrimental effects. As the risk maps depict, **significant growing areas such the Fenlands are expected to face the UK's highest risk level** of both drought and high temperatures.

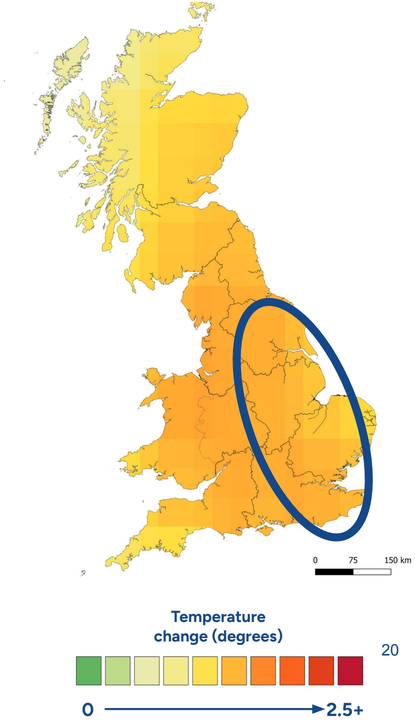
2040 summer - Rainfall change

Key indicator of drought



2040 summer - Mean temp increase

(from 1986 - 2006 baseline)



Extreme weather events can exacerbate barley's vulnerability at critical growing cycle phase

Incremental changes, such has the previously outlined 1.5 - 1.75C temperature increase projected in key barley growing regions by 2040, are likely to be exacerbated by accompanying sporadic extreme heatwave and drought events.

A 2018 study examining the effect of extreme weather on global beer supply assessed the increased likelihood of **concurrent drought and heat events in key barley growing regions** under various warming scenarios. As figure 4 shows, under a ~2.8C (RCP6.0) warming scenario, such events are expected to **experience a 17.8% mean increase in likelihood** between now and 2050.

Such extreme events have significant detrimental impacts on barley yields. Controlled experiments found that:

- Average grain yield decreased by 37% when a 10-day heatwave of 33/28 °C (day/night) was superimposed onto barley during flowering.[13]
- Barley plants exposed to severe drought stress (20% field water capacity) had a shorter duration of grain filling, significantly reducing grain yield.[14]

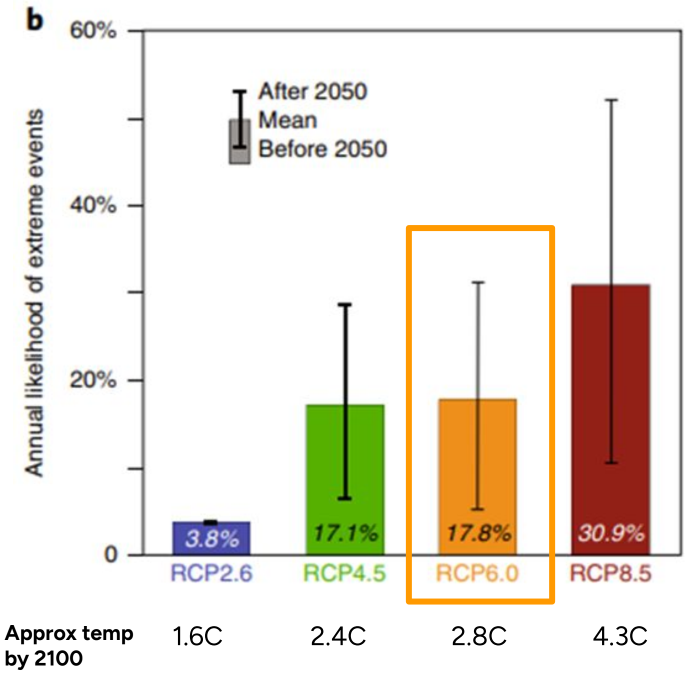


***Figure 4:** Annual likelihood of concurrent extreme events under each of the RCPs. Source:* [15]

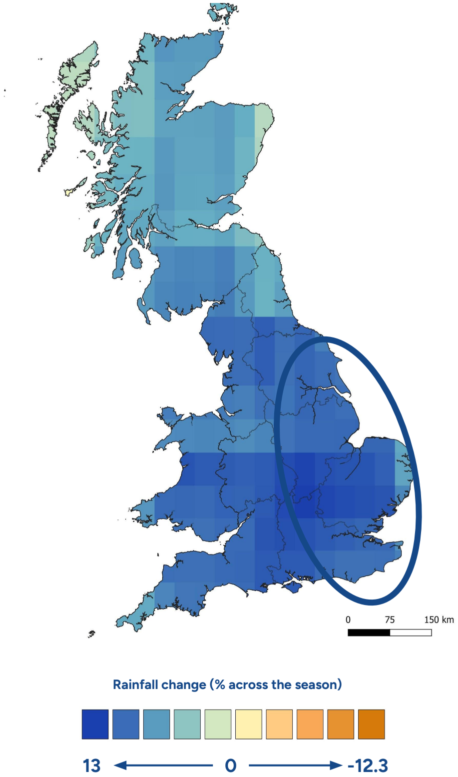
A trend towards milder, wetter autumn may increase rates of waterlogging in barley

Under the RCP 6.0 scenario, autumnal rainfall is projected to increase between 8% - 10.5% in key UK barley production regions by 2040. Average temperatures in autumn are also projected to rise between 1C - 1.25C from a 1986 - 2006 baseline, producing significantly wetter and warmer conditions

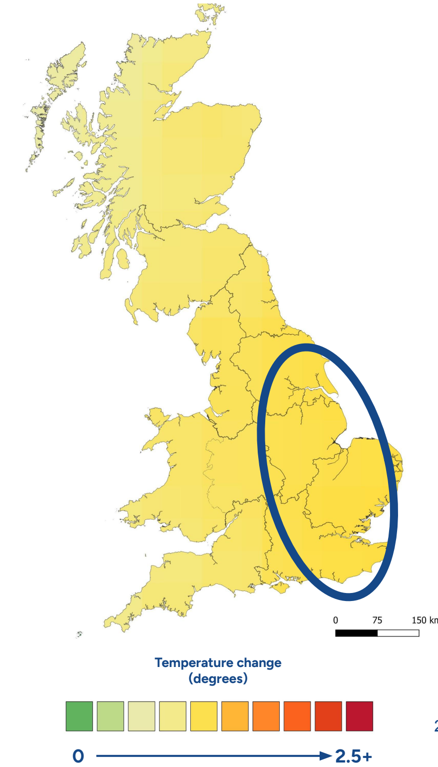
Increased precipitation can be detrimental to winter barley as **waterlogged soils prevent oxygen from reaching roots, which has potential to cause significant damage**. A recent field study revealed that prolonged waterlogging led to significant reductions in biomass, grain yield, and crop height for barley. [15] Additionally, there is a particular vulnerability in regions with heavy clay soils, such as those found in the Fens.

The humid conditions borne out of increasing autumn rainfall and higher temperatures also create an **environment favorable for soil-borne pathogens and fungal diseases, such as Fusarium,** which produce mycotoxins (e.g. T-2, HT-2 and DON), thereby posing a food safety hazard.

2040 autumn - Rainfall change



2040 autumn - mean temp increase
(from 1986 - 2006 baseline)



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Concentrated UK hop-growing regions exposed to risk of acute flooding events

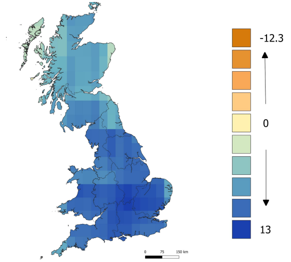
UK hops production is concentrated in Herefordshire & Kent. Both counties have mature rivers (the Wye and Medway) flowing through them, creating flood risk to surrounding areas. Under a 2.8C (RCP6.0) scenario, the area exposed to risk increases significantly, as depicted on the map.

As noted, autumnal **rainfall is expected to increase by 10+% in these regions by 2040**, meaning the risk of generalised, non river-specific flooding will also be elevated.

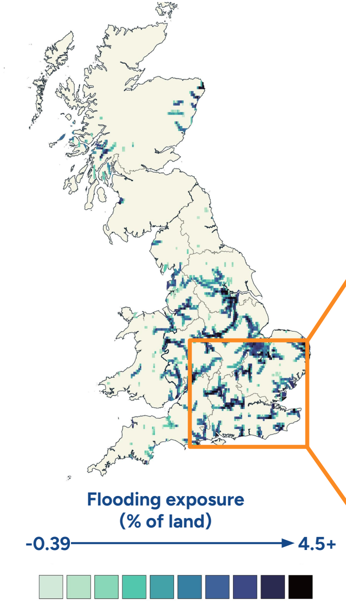
Flooding has negative impacts on both the quality and quantity of hop harvests. Soil saturation compromises root development. Submergence beyond 48-72 hours **can lead to complete loss of hop plants.**[16] Furthermore, multi-year maturation times for hops mean that after permanent damage from a severe flood event, yields may take years to recover.

Hop farmers rely on precise timings for planting and harvesting. Inability to access due to flooding during critical stages can have a significant impact on hop yield. Additional indirect impacts include the erosion of fertile topsoil, along with flood conditions inducing a higher prevalence of mold and fungal growth.

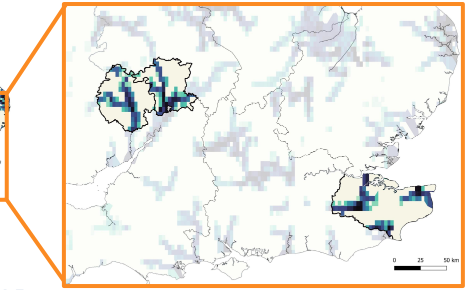
2040 Autumn - Rainfall change



2040 - Annual flooding



Hop growing regions

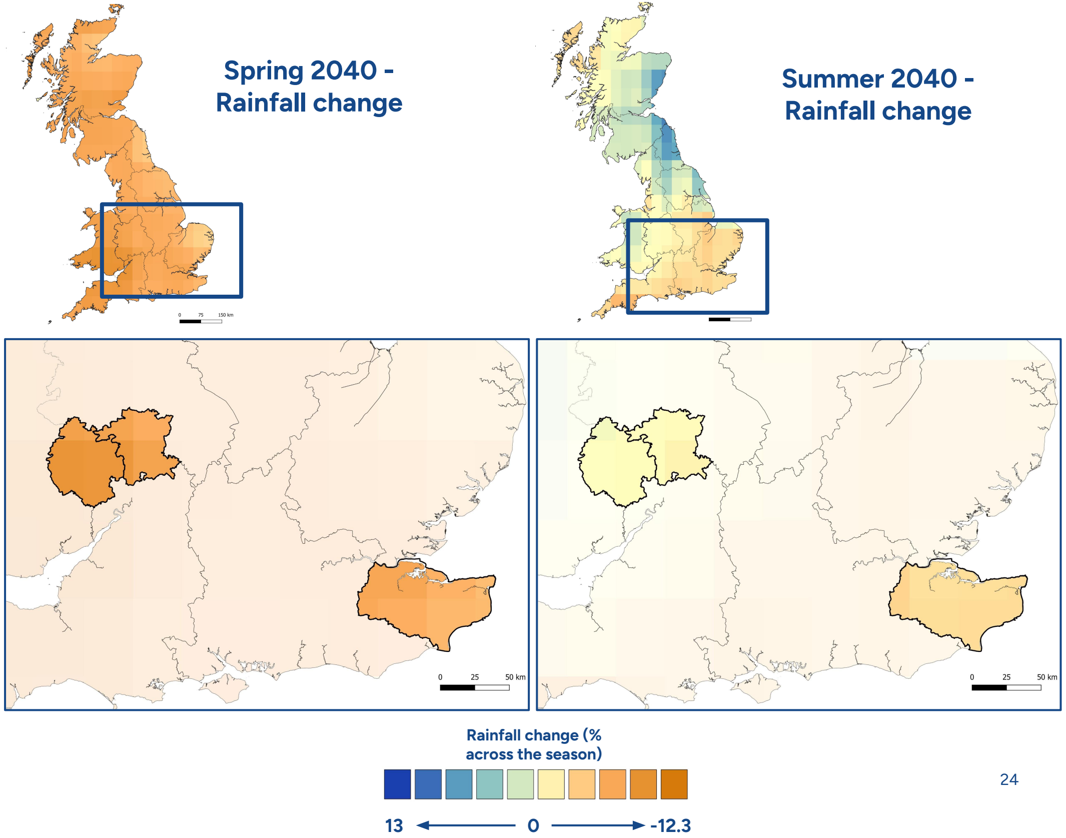


Reduced rainfall during Spring and Summer poses risks during hops' critical growing window

By 2040, under a 2.8C (RCP 6.0) scenario of warming, both spring and summer rainfall levels in key hop growing regions are projected to decrease. As depicted on the map shown, spring precipitation in the West Midlands could reduce by 10 - 12%.

Drier springs pose a risk to the **critical window of the hop growing cycle in April and May** (post emergence), when the hop vine is very water intensive. Hop plants have a short window to grow 12ft+ tall. However, if they experience water stress during this period, both yield and quality suffers.

During the summer, dry conditions can reduce the oil content in hop cones**, negatively affecting their aroma and flavouring.** The susceptibility to disease also increases in drought-weakened hop plants.

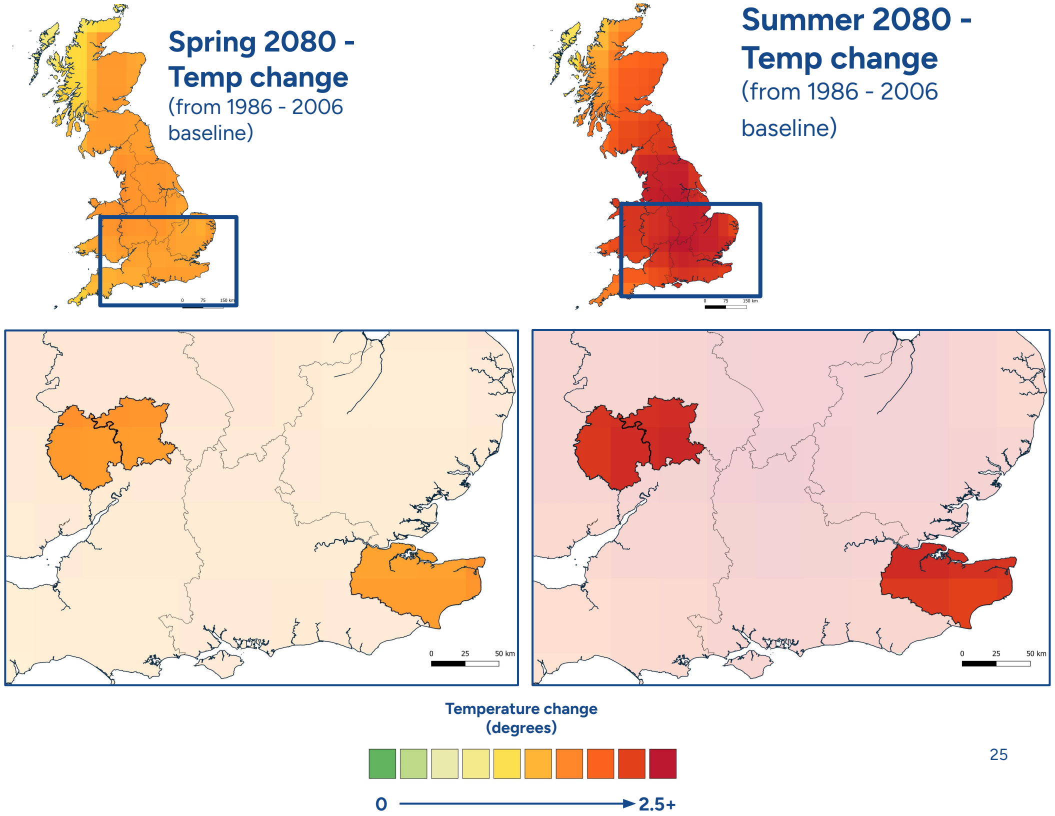


Hotter spring and summer temperatures can negatively affect both yield and alpha acid synthesis

Taking a longer-term view, by 2080, primary UK hop-producing counties, Kent and Herefordshire, are projected to face spring and summer temperatures which are 1.25C - 2.5C higher than a 1986 - 2006 baseline. This mean temperature increase can be expected to be **accompanied by an increased frequency of extreme heatwave** events.

Instances of extreme high temperatures can result in early spring flowering for hops, leading to reduced cone development and thereby detrimentally affecting yields.

In late summer (July - August), heat stress can reduce the synthesis of alpha acids in hops, lowering bitterness levels and therefore affecting their flavour profile. Certain **UK hop varieties - e.g. Fuggle - tend to be less heat-tolerant than some North American or Southern Hemisphere hops,** as they have evolved in temperate maritime climates.



Identifying location-specific risk hotspots through a vulnerability-severity analysis

Following the GIS mapping exercise, we carried out a severity-vulnerability assessment, to **identify the most material UK risk and location combinations** for hops and barley.

We allocated vulnerability scores for each of the three risks to both crops. We arrived at the score via a combination of desk-based literature research, consultation with sector experts, and 3Keel's previous work with brewers. The scores are shown in table 2; more detailed commentary is available in the Annex.

We then **combined the crop-specific vulnerability scores with the risk severity score**s, which emerged from the UK mapping exercise.

This approach allowed us to analyse the intersection of risk severity, crop vulnerability and region. We identified hotspots, which informed our priority adaptation measures and strategic sector recommendations.

Risk	hops		barley	
	Vulnerability Score	Comment	Vulnerability Score	Comment
Drought	4	Generally tolerant but new plants are susceptible	5	Short growing cycle reduces vulnerability however impact varies seasonally
High temp-erature	6	Moderately tolerant depending on when in the season the temperatures occur	6	Becomes vulnerable when temperatures exceed 30 degrees
Flooding	9	Multi-year maturation means that damage has a long recovery time	8	Susceptible to waterlogging which can be severe if prolonged

10 = Highly vulnerable

1 = Highly resilient

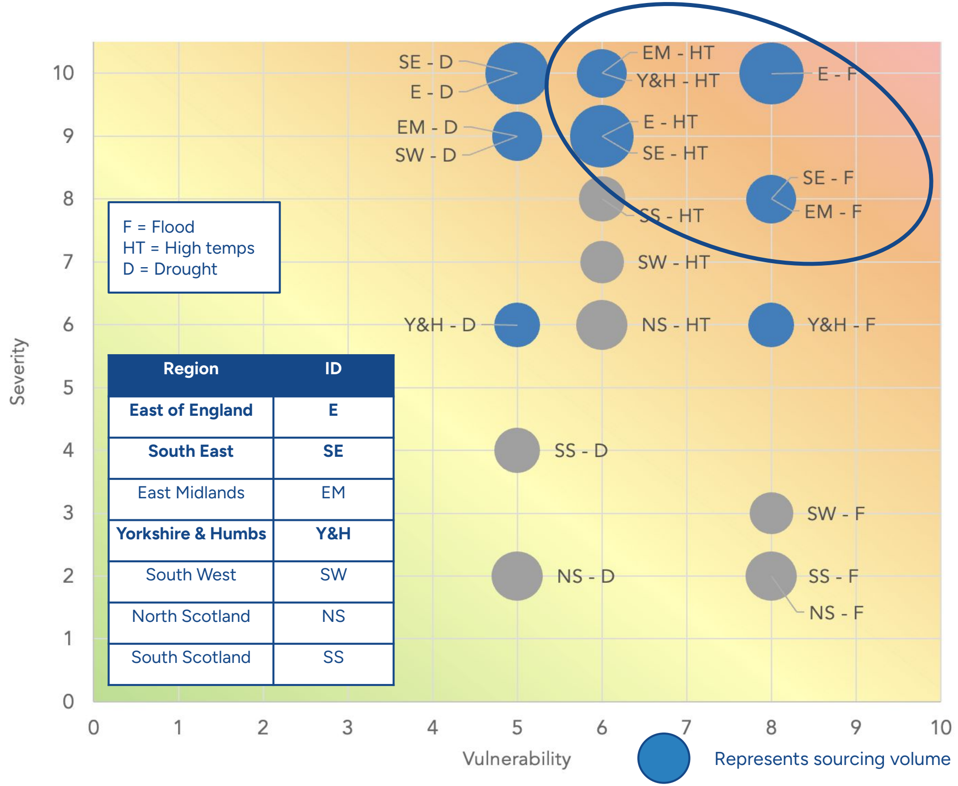
***Table 2:** Summary of crop vulnerability scores*

Highest risk severity-vulnerability levels concentrated in significant UK barley growing regions

The severity-vulnerability matrix in Figure 5 highlights the combined ranking of expected risk severity (in 2080) and crop vulnerability across key UK barley sourcing geographies.

The results highlight barley's vulnerability to high temperatures and flooding, which are projected to be the **most severe in the East of England, with the South East and East Midlands also scoring highly** (circled in figure 5). As depicted via the size of the bubbles, high volumes of malting barley are currently grown in these regions.

There are incidences where a given region scores highly for all three risks analysed. For example, the East of England is projected to be exposed to severe drought, flooding and high temperatures. Although it is likely that these risks would materialise throughout different phases of the barley growing cycle, their **compounding impacts may further increase barley's future vulnerability** in the region.



Region	ID
East of England	**E**
South East	**SE**
East Midlands	EM
Yorkshire & Humbs	**Y&H**
South West	SW
North Scotland	NS
South Scotland	SS

Figure 5: *Combined ranking of expected risk severity (in 2080) and crop vulnerability in key UK barley sourcing geographies*

Intensive flooding poses material risk in UK hop regions, with high temperatures gradually impacting flavours

We carried out a similar severity-vulnerability assessment for hops but focused on the South-East and West Midlands, given the concentration of hop growing in these regions.

In both regions, we identified flooding as a risk hotspot for hops, due to hops' vulnerability to severe flood impacts. While **flooding is typically sudden, short-term, and localised**, it is can be highly destructive even over a short period. Recovery can be difficult, as affected hops may be lost entirely, requiring replanting.

Hops were not deemed as vulnerable to high temperature and drought, as these risks often manifest as more gradual and longer-term phenomena over extended periods. However, these risks should not be ignored, given their projection to increase in severity in the South-East and West Mids. As noted, hotter temperatures, particularly during summer months can **reduce the synthesis of alpha acids in hops, negatively affecting quality**.

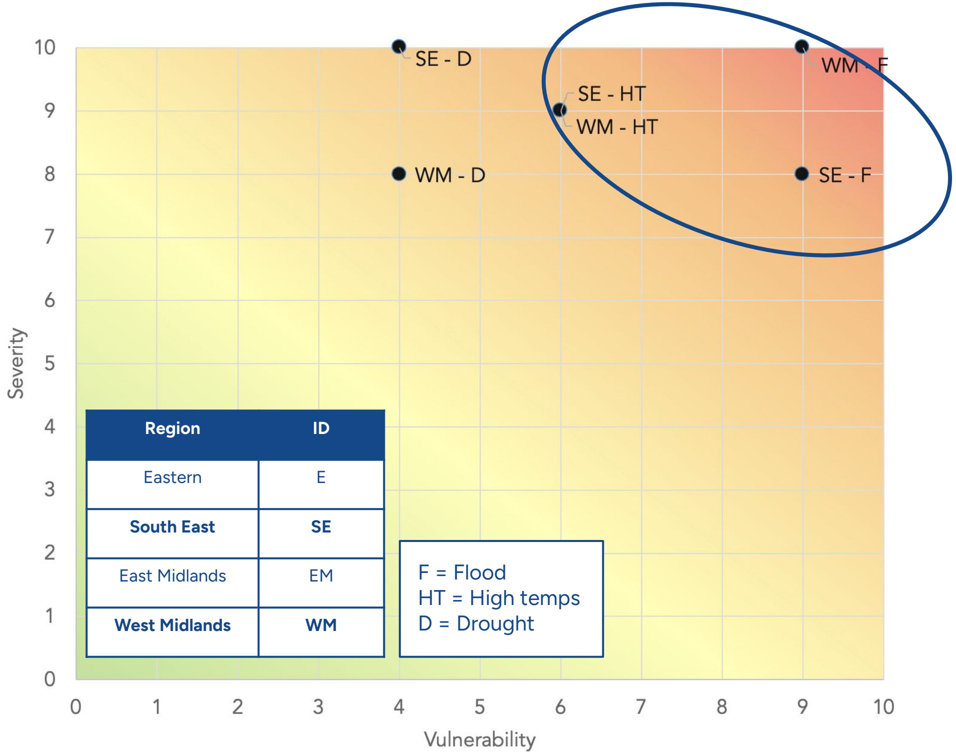


Figure 6: *Combined ranking of expected risk severity (in 2080) and crop vulnerability in key UK hops sourcing geographies*

RISK & IMPACT ASSESSMENT

International sourcing risk

International barley growing regions are projected to face risk from drought and heat

While the UK currently only sources a small percentage (<2%) of it's barley internationally, the **interconnected nature of global cereal markets** means that climate-related risks elsewhere can cause pricing shocks and potential future supply disruptions.

Recent research projects a ~18% mean annual likelihood of concurrent drought and heatwave occurring in key barley growing regions under RCP 6.0 in coming decades, resulting in a projected ~10% reduction in global malting barley yield. [17]

UK's imported barley is grown in the EU, in regions exposed to either current and future risks. For example:

Spain: Crop yields strongly limited by reduced availability of water under projected climate conditions, potentially experiencing a 10%+ yield reduction by 2050. [18]

France: In 2024, excessive rainfall led to a 22% decrease in cereal production in France, with barley among the affected crops. [19]

Germany: Under high warming scenarios, frequent droughts and heatwaves are projected to limit yields. One assessment of risks to barley and the resulting impacts on volumes used for brewing, projected supply reductions in Germany of between 27-38% by the end of this century. [15]

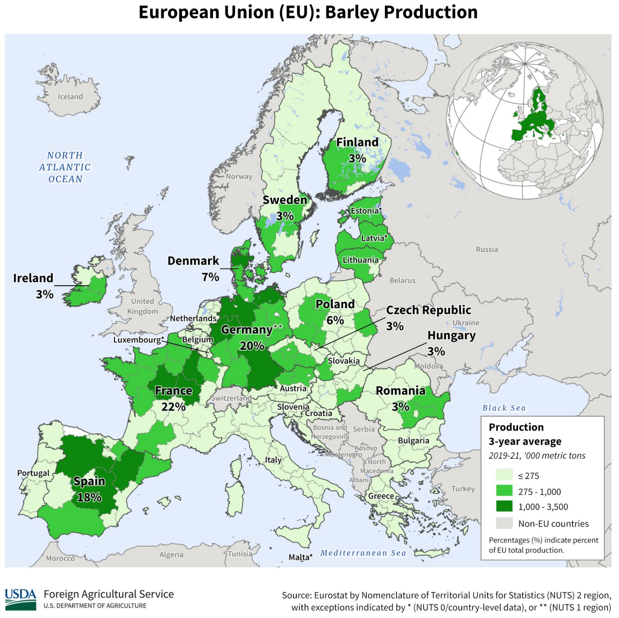


***Figure 7:** 3 year barley production in the EU, proportionally split by member countries. Source:* [20]

Hops face significant climate risks in key European sourcing hotspots

Key Continental European hop growing regions face significant climate risks. The increasing occurrence and **severity of droughts and heatwaves is already having a detrimental impact** on European hop yield and quality. A recent study found that hop productivity in Germany, Czech Republic and Slovenia has declined by almost 0.2 t/ha/year when comparing data before and after 1994. [7]

Looking ahead, these risks are set to worsen, with **a projected 4–18% decline of hop yield across the main EU growing regions by 2050**. Table 3 highlights the scale of the area and corresponding level of yield loss expected. Almost a quarter of EU commercial hop growing regions face a moderate loss of yield, with 7.2% of area projected to experience very high yield loss. [21]

Table 3: Estimated area and severity of yield losses in the EU

% of EU growing area	Projected severity of yield loss
22.4%	Moderate
12.5%	High
7.2%	Very high

As well as negatively impacting yields, drought and heatwave events also **decrease the alpha-acid content of hops, thereby affecting flavour profiles**. Within key EU growing regions, the alpha acid content of hops is predicted to decline by 20–31% by 2050. [7]

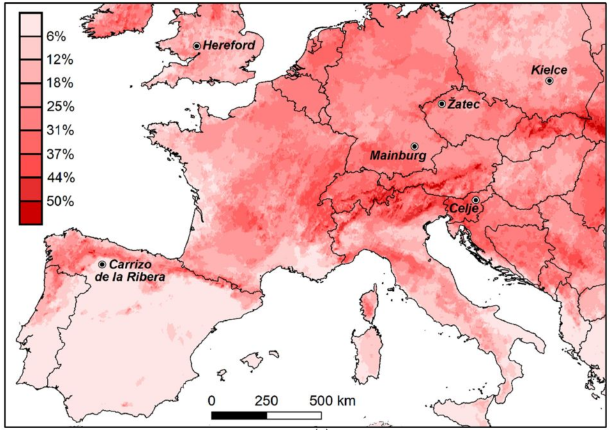


Figure 8: *Assessment of* ***historical*** *(1999 - 2018) degree of risk of lower hop yields based on combined max temp and precipitation anomalies. Source:* [21]

Unique hop varieties in Europe under threat from drought and heat stress

Each hop variety holds unique aromatic and flavor characteristics and the cultivation of a particular hop variety is restricted by location-specific climate, soil composition, and growing conditions. UK hops are prized for their earthy, herbal, and floral qualities, but they are not always suitable for the high-intensity hop character needed in modern styles. In comparison, German hops, particularly high-alpha varieties, are a cost-effective way to provide bitterness in beer.

As noted, the projected level of risk and impact severity varies significantly between European regions. Recent research found that **Germany and Czech Republic appear to be more vulnerable to dry-heat stress for hop growing** than the UK and Poland [21], threatening important varieties used by UK brewers.

Czech Republic - Irregular rainfall and depleted groundwater reserves **threaten delicate aroma hops like Saaz**, which are highly vulnerable to heat and water stress. Research shows the most frequent occurrences of extreme heat in Czech Republic hop growing regions take place between July and August during the flowering to cone development hop growing phases. [21] This may result in early ripening and a corresponding decline in quality. [7]

Germany - **Prolonged heat waves and drought** have resulted in a decline in hop output in recent years, with a further 10 - 15% yield decline projected by 2050. The **Hallertau region in Bavaria** is particularly vulnerable to heat stress, ranking second in its frequency of hot dry conditions out of 14 regions in 2015. [21] These conditions also threaten the alpha content and essential oils critical for bitterness. Reduced availability of European hop varieties, could **challenge UK brewers currently reliant on traditional European flavour profiles**.

Serious risks also present in US Pacific Northwest, despite irrigation mitigating worst short-term impacts

More than 50% of the UK brewing industry's hop imports are grown in the US. The primary US hop growing area, the Yakima Valley, is a semi-arid region receiving <10 inches of rain annually. [22] Steady irrigation from snow-fed rivers and aquifers has historically allowed high yields of water-intensive hops, even in dry summers. However, rising average temperatures, reduced snowpack & melt from the Cascade Mountains, and **more frequent droughts are severely impacting water availability** in the region.

Despite this, Pacific Northwest hops have remained **relatively resilient to water stress so far - primarily due to the use of irrigation**. 100% of the US hops acreage is irrigated, versus only ~20% in Europe. [23] This irrigation explains the higher levels of productivity in US hop-growing regions than EU in recent years, particularly in 2022 (see table 4).

Looking ahead, changes in precipitation timing and increased competition for water (e.g. for cities and fisheries) creates **uncertainty around future irrigation supply**. Local summer stream flows are projected to be substantially lower by 2050. [24] Increased irrigation costs are likely to continue to push up US hop prices in the short-term, while **longer-term yields and alpha acid content of US-grown hops may decrease** significantly.

Hop production region	2022 avg. yield	2023 avg. yield
US	1.86 mt / ha	2.09 mt / ha
Europe	1.50 mt / ha	1.83 mt / ha

Table 4: *Comparison of average yield in US and Europe between 2022 and 2023*

RISK & IMPACT ASSESSMENT

Impacts on the UK brewing sector

Drought and flooding present significant risk to barley both in UK and internationally

Eastern England most vulnerable to risks:

Four regions on the UK east coast currently supply 65+% of the UK brewing sector's malting barley. Under a 2.8C (RCP 6.0) warming scenario, these regions are projected to experience higher severity of risks than most of the UK. For example:

- **Hotter, drier summers**:
  - Projected 2.2 - 7% rainfall reductions and 1.5 - 1.75C temperature increase during summer by 2040
  - Mean temperature rises are expected to also cause more frequent and intense extreme heat and drought events
  - Drought and higher temperatures during grain-filling period can reduce yield and degrade Malting quality
- **Warmer, wetter autumns**:
  - Average autumn rainfall projected to increase by between 8 - 10% by 2040
  - Alongside average increase, intensive precipitation events also expected under the RCP 6.0 scenario
  - Waterlogging can damage barley roots, and humid conditions lead to soil-borne diseases such as Fusarium

Barley International risks

EU barley-growing regions **face more material risks**, with drought, high temperatures and flooding already manifesting, particularly in Southern Europe. Although the UK brewing sector is **not currently heavily reliant on barley imports**, expected future constraints on barley production in Europe and further afield will have implications for UK brewers (see next page).

Average trends and accompanying extremes

While some studies project that increased warming could lead to a *short-term* boost in UK barley yields [25], unpredictable extreme events both domestically and overseas are also set to increase in frequency and severity, with significant corresponding production losses.

Compounding climate risks expected to cause malting barley price volatility and quality issues

The chronic and acute climate risks projected to affect both UK and international barley production are expected to profoundly impact the UK brewing industry via:

Price volatility

The interconnected nature of **global cereal markets** means that disruptions from extreme weather or geo-political events impact prices worldwide. For example, in 2018, malting barley prices rose by ~30% primarily due to severe drought and heatwave in Europe. [5] The dramatic spike in price following the invasion of Ukraine in early 2022 shows the interconnectedness of malting barley prices to other cereals such as wheat.

Under high warming scenarios, further extreme weather and geo-political instability are both expected to increase significantly. malting barley input costs for **UK brewers are therefore vulnerable to shocks** from barley yield reductions **both domestically and overseas**

Variability in malting barley quality

Drought and heat stress leads to **higher nitrogen concentration** in barley, reducing its suitability for brewing and **disrupting predictable supply** to the sector. If overall domestic barley yields are not detrimentally impacted in the short-term, the crop quality is still vulnerable to extreme weather events increasing in frequency and severity.

Global supply squeeze may threaten UK brewers' barley sourcing in the long term

Potential diversion of UK barley from brewing

Under high warming scenarios, UK agricultural land use is expected to be altered significantly. For example, **prioritising barley for animal feed or direct food production over brewing** would be likely.

- A recent UK study [2] used a food-balance approach to examine expected impacts of climate change and mitigation policies on malt barley supplies.
- Results show large **deficits in malt barley supplies** for all combinations of climate change, land use and population by 2050, with adverse implications for the malting industry.

Overseas supply cannot be relied upon as a substitute

If the UK brewing sector's current UK-grown volumes of malting barley are restricted in the future, it is unlikely that significant global supplies will be readily available to backfill the shortfall.

- Research found that future projected drought and heat events will not only lower the total availability of barley for key growing countries, but will also **reduce the share of barley used for beer production**. [15]
- At the global level, the research finds that most severe climate events (that is, RCP8.5 scenario) cause the barley supply to decrease by 15%, but the share of barley-to-beer to decrease by 20%.
- Barley-to-beer shares shrink more than barley-to-livestock shares, showing that food commodities would be prioritised over luxuries such as beer during extreme events years.

Need for rapid rollout of barley growing resilience measures

The findings outlined above underscore the importance of urgent action among the UK brewing sector to implement upstream adaptation measures and build resilience in existing barley supply chains if future supplies are to be safeguarded.

Risks to hops particularly prevalent in international sourcing hotspots

Projected risks to UK hop growing

UK hops production has reduced significantly in recent decades and is now concentrated in specific areas primarily in Kent and Herefordshire. Under a 2.8C warming scenario (RCP 6.0) the most material risks expected to affect hops in these areas include:

- **Flooding:** localised river basin flooding and waterlogging from extreme precipitation events compromise root development or cause irreversible damage.
- **Drier spring & summer**: By 2040, spring rainfall set to reduce by 5 - 8%, this may lead to detrimental impacts on hops during their water-intensive growth period.
- **Hotter spring & summer**: Higher temperatures may affect the development of alpha acids in hops, negatively impacting their flavour profile

Severe risks in key international sourcing locations

The UK brewing sector is highly dependent on imported hops, particularly those grown in the **US (Pacific Northwest) and Germany.** These regions are already facing significant risks, which are set to become more severe in the next decades:

- **Severe drought** - to date, worst effects in US have been mitigated by irrigation, but this will not be a long-term solution due to expected changes in precipitation and increased competition for water
- **Extreme temperatures -** already impacting both yield and flavour profile, set to worsen in US and continental Europe

Location specificity of hop varieties poses challenges to risk-driven sourcing shifts

Shortages of key hop varieties may cause UK supply disruption

- The concentration of hop cultivation in small geographic regions makes these yields more vulnerable
- This is a particular risk given the sensitivity of hop flavor profiles and **inability to easily change recipe formulation**
- In Europe, there is a high likelihood of export reluctance in instances of hop shortages given European brewers' reliance on certain varieties to meet protected geographical indication (PGI) recipe requirements

Future price volatility expected

- Hop pricing varies significantly depending on variety, and fluctuates quite dramatically depending on the world supply: current global prices range from ~€1/kg to ~€15/kg
- Damaging weather events in growing regions such as USA and Europe would reduce overall supply, thereby driving up costs.
- Traditional hop-growing areas expected become less viable, potentially forcing **production location shift**. As hops are a perennial crop, such shifts would **entail high initial costs and uncertain productivity**, adding to price volatility.

Potential to increase UK hop sourcing

- Compared to sourcing regions such as USA and parts of Europe, **UK may be more viable for hops growing in coming decades** [21] → but potential benefits of domestic production need to be **balanced with flavour profile needs** of the sector
- Taking advantage of potentially more favourable UK growing conditions would only be possible if sufficient risk mitigation measures, including targeted breeding programmes, are implemented to build resilience

03. Priority adaptation measures

Identifying priority adaptation measures to tackle hops and barley climate risk

Given the increasing climate pressures on barley and hop production, including drought, flooding, and extreme temperatures, **targeted adaptation strategies at the farm level are essential** for ensuring long-term resilience of supply. This section identifies the most effective agronomic measures to mitigate the material risks outlined in Section 2. As key beneficiaries of a stable and sustainable ingredient supply, brewers have a direct responsibility to drive uptake of these measures by supporting farmers with financial incentives, long-term contracts, and knowledge-sharing initiatives.

We **identified the 10 priority adaptation measures** via desk-based research, consultation with key industry stakeholders (including Charles Faram and MAGB), and insights drawn from 3Keel's expertise in agricultural resilience and climate adaptation. Most measures are applicable to both crops, however, we have noted where a given measure is expected to be particularly suitable for mitigating risk in either hops or barley growing.

The following slides **evaluate the adaptation measures based on their benefits** over time, cost implications, barriers to implementation and potential co benefits for GHG emissions, biodiversity and water. We have assessed co-benefits against a five-point scale (1 - very high benefits, 2 high, 3 moderate, 4 low and 5 minimal). This structured evaluation helps determine which adaptations offer the best balance of feasibility and impact for farmers and the broader brewing supply chain.

Water Management

Climate Resilient Crops

Soil Health & Regeneration

Technology & Monitoring

10 interconnected risk adaptation measures

Figure 9 depicts the ten priority agronomic adaptation measures identified and illustrates their interconnectedness. They are grouped into distinct categories: Water Management, Climate Resilient Crops, Soil Health & Regeneration and enabled by over-arching Technology & Monitoring.

Please note, on the following pages the adaptation measures are not listed in order of priority.

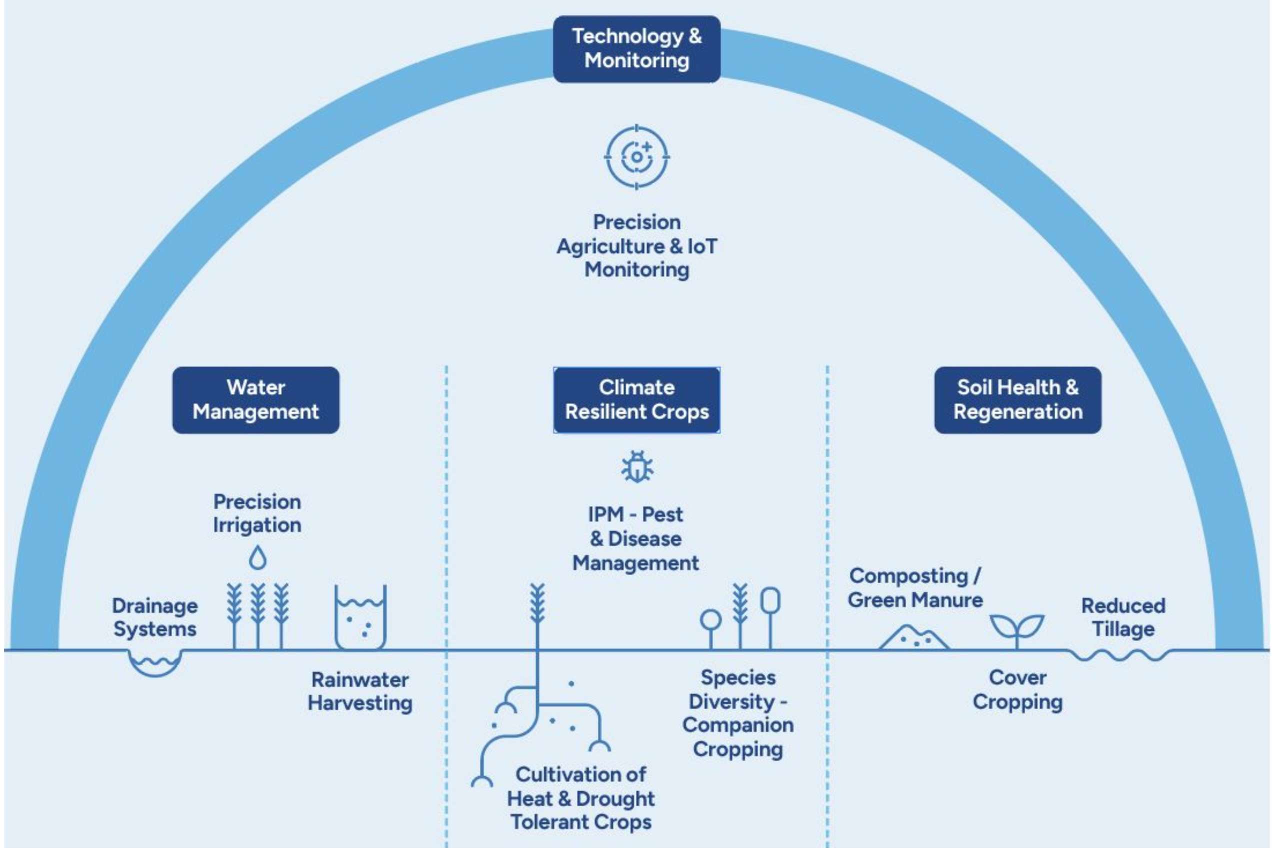


Figure 9: *10 priority agronomic measures for mitigation of material risks. Source:3Keel*

Adaptation Measure - Drainage Systems

Water Management

Description	Risks Mitigated	Co-Benefits (1 / 2 / 3 / 4 / 5)
Applicable to both barley and hops. Installation of new / enhanced drainage systems (plus repairing of existing) for improved surface water runoff management and to prevent waterlogging and mitigate flood risks (especially in flood-prone areas like Kent / Herefordshire). Will help improve land access with machinery, avoiding delays with drilling and/or input application, critical to crop quality.	**Flooding** - Helps prevent root damage by allowing excess water to drain efficiently. - Reduces soil erosion by: controlling runoff, preserving topsoil and maintaining fertility.	Helps prevent water logging while maintaining appropriate soil moisture levels aiding retention. Reduces the risk of runoff (sediment/nutrients) during heavy rains, preserving local water quality. Reduces prolonged water saturation, which can harm beneficial soil microorganisms and earthworms.

Cost Scale	Barriers	Water	Biodiversity	Emissions
		2	2	3
 High	- Requires significant upfront investment in materials, labour, and equipment. - Can require regular / routine maintenance. - Emotive if local priority is to aid water retention and create natural flood management.	**Materialisation of Benefits: Medium-Term (3–5 Years)** Adaptation to deliver tangible benefits within a medium timeframe of 3–5 years. This period reflects the time required for changes in on-farm practices, infrastructure investments, and agronomic improvements to translate into measurable resilience.		

Adaptation Measure - Precision Irrigation

Water Management

Description	Risks Mitigated	Co-Benefits 1 2 3 4 5
Irrigation (but more specifically, precision irrigation) uses advanced technologies such as controlled drip irrigation lines (particularly suitable for hops), soil moisture sensors, Internet of Things (IoT) devices, and weather forecasting to deliver water efficiently and at optimal times. This method ensures that crops such as barley and hops receive only the necessary amount of water, reducing waste and improving plant health.	**Drought** - Addresses water stress during critical growth periods, especially for hops (April–May) and barley (grain-filling period) - By providing consistent soil moisture levels, precision irrigation reduces the impact of evapotranspiration.	Reduces water use by up to 30–50% compared to traditional irrigation systems. Biodiversity - minimises over-extraction of water from rivers and aquifers. Lowers energy consumption associated with water pumping and irrigation. Reduces the loss of nutrients, maintaining soil fertility and reducing the need for chemical fertilisers (lowering emissions).

Cost Scale	Barriers
 Medium	- Initial setup costs for sensors, automated irrigation systems, and related infrastructure. - Expensive for small-scale farmers without financial support. - Requires training in using and interpreting data. - Remote farms may face challenges with IoT device connectivity.

Water	Biodiversity	Emissions
1	2	3

Materialisation of Benefits: Medium-Term (3–5 Years)

Adaptation to deliver tangible benefits within a medium timeframe of 3–5 years. This period reflects the time required for changes in on-farm practices, infrastructure investments, and agronomic improvements to translate into measurable resilience.

Adaptation Measure - Rainwater Harvesting

Water Management

Description

Applicable to both barley and hops, rainwater harvesting involves capturing and storing rainwater runoff in on-farm reservoirs or tanks, for future use. This ensures a reliable water supply during dry periods, reducing reliance on external water sources and mitigating water scarcity.

Risks Mitigated

Drought
- Providing a supplementary water source during prolonged dry spells. Reducing dependency on rivers, aquifers, and other limited water sources.

Flooding
- Can reduce surface runoff during heavy rainfall, lowering the risk of localised flooding.

Co-Benefits

1	2	3	4	5

Efficient water management - optimises water use, preserving local water resources.

Biodiversity - reservoirs can support local wildlife.

Emissions - reduces energy use associated with pumping water from distant sources / water abstraction from rivers.

Cost Scale

Medium

Barriers

- Costs depend on reservoir size, site preparation, and materials used. Excavation, lining, and installation of pumping systems can be expensive.
- Planning permissions and water abstraction licenses may be required.
- Requires ongoing maintenance to ensure water quality and system efficiency.

Water	Biodiversity	Emissions
2	3	2

Materialisation of Benefits = Short-Term (1-2 years)

Adaptation to deliver tangible benefits within a short time frame of 1-2 years. This period reflects the fact that benefits can begin to show within a single growing cycle.

Adaptation Measure - Cultivation of Drought & Heat Tolerant Varieties

Climate Resilient Crops

Description	Risks Mitigated	Co-Benefits
The development and adoption of drought and heat-tolerant crop varieties to ensure resilience against climate-induced stressors. There is a growing need to breed barley and hop varieties that have deeper root systems, efficient water use, and tolerance to high temperatures, helping maintain yield and quality in challenging environments. Greater urgency in hops - Humulus lupulus var. neomexicanus is specifically adapted to arid conditions and exhibits deep root systems, allowing it to access water in lower soil layers.	**Drought** - Leading to stunted growth, and lower yields. - Stressed plants are more vulnerable to pests/diseases. **Higher Temperatures** - During flowering or grain-filling can impair pollination, reduce kernel development in barley, and lower alpha acid synthesis in hops.	Water efficiency / conservation - such crops would require less supplemental irrigation, reducing pressure on local water resources. Reduced emissions via lessening the dependency on irrigation lowers energy costs associated with pumping and transporting water. Varieties that thrive under drought and heat stress reduce the need for chemical inputs (e.g., fertilisers, pesticides), supporting local biodiversity.

Co-Benefits scale: 1 | 2 | 3 | 4 | 5

Water	Biodiversity	Emissions
1	2	2

Cost Scale

Medium

Barriers

- High R&D costs.

- Long breeding cycles (new varieties require several years of trials and approvals).

- Adoption reluctance for new varieties.

- Market adoption / performance / flavour profiles.

Materialisation of Benefits = Long Term (5 years+)
Adaptation measure to deliver tangible benefits over a long-term timeframe of 5 years or more. This period reflects the time required for systemic changes to fully materialise and provide lasting resilience.

Adaptation Measure - IPM - Pest & Disease Management

Climate Resilient Crops

Description	Risks Mitigated	Co-Benefits (1 2 3 4 5)
Integrated Pest and Disease Management (IPM) is a more holistic approach to controlling pests and diseases by combining biological, cultural, physical, and chemical methods. It prioritises sustainable practices to minimise environmental impact while maintaining crop health and yields.	**Higher Temperatures** - Allow pests like aphids and mites to overwinter, increasing infestations in spring. **Flooding** - Wetter more humid conditions promote fungal diseases like Fusarium head blight (barley) and downy mildew (hops) plus the risk of mycotoxins.	Encourages natural predators (e.g., ladybirds, lacewings) and reduces reliance on broad-spectrum pesticides. Emissions - reduces the need for crop treatment / applications. Water - reduces risk of contamination via run-off.

Cost Scale	Barriers	Water	Biodiversity	Emissions
		3	1	2

Cost Scale

Medium

Barriers

- Farmers may lack expertise in biological control methods or monitoring technologies.

- Mind-set change - increased monitoring / attention to detail.

- Effective IPM requires consistent monitoring and adapting practices, which can be labor-intensive.

Materialisation of Benefits = Short-Term (1-2 years)

Adaptation to deliver tangible benefits within a short time frame of 1-2 years. This period reflects the fact that benefits can begin to show within a single growing cycle.

Adaptation Measure - Species Diversity / Companion Cropping

Climate Resilient Crops

Description	Risks Mitigated	Co-Benefits (1, 2, 3, 4, 5)
Increasing species diversity through crop rotations (barley specific), cover cropping, companion cropping and agroforestry (hops) can significantly enhance on-farm biodiversity. This holistic approach creates a synergistic agricultural system that promotes species diversity above and below ground, while improving soil health and ecosystem resilience.	**Flooding** - Crop rotations (barley) and cover crops improve soil organic matter, nutrient cycling, and structure. **Drought** - Deep-rooted cover and companion crops improve water infiltration.	Biodiversity - more diverse plant species from crop rotations, cover crops, and companion cropping will attract a wide range of pollinators and natural pest predators. Water - cover crops / companion crops enhances soil organic matter and structure, allowing soil to retain more water during droughts. Emissions - leguminous crops in rotation and as companion crops can help fix nitrogen naturally, reducing reliance on synthetic fertilisers.

Cost Scale	Barriers	Water	Biodiversity	Emissions
		2	1	2
 Low	- Conventional farm equipment may not be suitable for managing multi-crop or agroforestry systems. - Some regenerative practices, such as companion or cover cropping, provide more medium to long-term benefits but may not yield immediate financial returns. - Farmers often need to be focused on short-term profitability and may have to prioritise yield maintenance over regenerative practices.	**Materialisation of Benefits: Medium-Term (3–5 Years)** Adaptation to deliver tangible benefits within a medium timeframe of 3–5 years. This period reflects the time required for changes in on-farm practices, infrastructure investments, and agronomic improvements to translate into measurable resilience.		

Adaptation Measure - Soil Health / Regenerative Ag - Composting / Green Manure

Soil Health & Regeneration

Description	Risks Mitigated	Co-Benefits (1 / 2 / 3 / 4 / 5)
The application of organic matter including manure and compost, to soil can be used as an alternative to nitrogen fertiliser for both hops and barley to improve the nitrogen content of soils. Hop plant biomass that is left following harvesting and processing can be composted and applied to fields following harvest, bringing circularity to the system. These practices enhance soil health, conserve moisture, and protect crops from extreme weather impacts, making them vital tools for climate adaptation.	**Drought** - Mulching around hops reduces water loss from evaporation and improves soil moisture retention. - Composting improves soil structure, reducing susceptibility to erosion during heavy rainfall. - Organic matter enriches the soil, enhancing fertility and resilience over time.	Biodiversity - boosts soil microbial activity, supporting a healthier and more diverse ecosystem. Emissions - helps to sequester carbon and reduce need for inorganic fertiliser. Water - enhances infiltration rates and holding capacity. Waste efficiency - can repurpose agricultural and brewery by-products, such as spent grains.

Cost Scale

Low

Barriers

- Requires low-cost raw materials but may involve equipment or labor for processing.
- Farmers may lack expertise in proper composting or mulching techniques.
- Consistent access to organic materials may be a challenge, especially for large farms.
- Introduction of contaminants / increased disease risk.

Water	Biodiversity	Emissions
2	2	1

Materialisation of Benefits = Short-Term (1-2 years)

Adaptation to deliver tangible benefits within a short time frame of 1-2 years. This period reflects the fact that benefits can begin to show within a single growing cycle.

Adaptation Measure - Soil Health / Regenerative Ag - Cover Cropping

Soil Health & Regeneration

Description

Cover cropping involves planting non-cash crops, such as clover, vetch, or rye, in between primary crop cycles to protect and enrich the soil. While primarily attributable to barley, cover crops can also be planted in hop fields to minimise the amount of bare soil left exposed.
Cover crops can reduce soil erosion, improve soil water retention, and can reduce the need for artificial fertilisers.
Some brewers (see Asahi) are trialling wildflower interventions in hop alleyways (across EU & in UK) to investigate the benefits for hops and biodiversity.

Risks Mitigated

Flooding

- Helps prevent topsoil from being washed / blown away during heavy rainfall, reducing the impact of flooding.

Drought

- Increases soil organic matter and water retention. Helps to stabilise soil structure.

Co-Benefits

1	2	3	4	5

Biodiversity - provides habitats for pollinators and beneficial insects, improving ecosystem resilience.

Emissions - sequesters carbon in the soil, reducing greenhouse gas emissions.

Soil health - improves nutrient cycling and microbial activity, boosting long-term productivity.

Leguminous cover crops can fix nitrogen, reducing the need for synthetic inputs.

Cost Scale

Low

Barriers

- Seed costs vary by cover crop species, and some may require additional management, such as mowing.
- Farmers may lack experience in selecting appropriate cover crops or managing them effectively.
- Timing and integration with existing crop cycles can be complex.
- Farmers (hops) may perceive cover crops as competing with cash crops for space or resources. Or introducing unnecessary weed / pest burdens.

Water	Biodiversity	Emissions
2	1	2

Materialisation of Benefits: Medium-Term (3–5 Years)

Adaptation to deliver tangible benefits within a medium timeframe of 3–5 years. This period reflects the time required for changes in on-farm practices, infrastructure investments, and agronomic improvements to translate into measurable resilience.

Adaptation Measure - Soil Health / Regenerative Ag - Reduced Tillage

Soil Health & Regeneration

Description	Risks Mitigated	Co-Benefits (1 2 3 4 5)
Reducing the frequency and intensity of tillage reduces disturbance to soil structure and maintains a higher proportion of crop residues in the soil. This approach serves to increase soil organic matter content, maintain soil ecological communities and reduce soil erosion and carbon release.	**Drought** - Enhances soil moisture retention, reducing water stress during dry periods. - Helps to maintain organic matter and nutrient cycling. **Flooding** - Protects against topsoil loss during heavy rainfall events.	Biodiversity - promotes soil microbial diversity and health. Emissions - reduces fuel use associated with frequent tillage and helps maintain sequestered carbon. Resilience - builds soil resilience to withstand both drought and flooding.

Cost Scale	Barriers
 Medium	- Requires investment in specialised equipment (e.g., direct seed drills) but reduces operational costs over time. - Transition, the early years of reduced tillage may result in lower yields as soils adjust to the new system.

Water	Biodiversity	Emissions
2	2	2

Materialisation of Benefits: Medium-Term (3–5 Years)

Adaptation to deliver tangible benefits within a medium timeframe of 3–5 years. This period reflects the time required for changes in on-farm practices, infrastructure investments, and agronomic improvements to translate into measurable resilience.

Adaptation Measure - Data and Monitoring Systems / Precision Agriculture

Technology & Monitoring

Description	Risks Mitigated	Co-Benefits (1 2 3 4 5)
Data and monitoring systems, including precision agriculture tools and IoT devices, use advanced sensors, GPS technology, and real-time analytics to better monitor soil conditions, water availability, pest pressures, and weather patterns. These systems enable farmers to make more informed decisions, optimising resource use and improving resilience to climate risks.	**Drought** - Real-time soil moisture data to guide irrigation and reduce water stress during critical growth periods for hops and barley. **Higher Temperature** - Temperature and humidity to identify high-risk periods and implement protective measures.	Optimises water use - reduces irrigation needs by ensuring water is applied only where and when it's necessary. Lowers energy use associated with over-irrigation and unnecessary field operations. Reduces overuse of pesticides and fertilisers, protecting local ecosystems and pollinators.

Cost Scale	Barriers	Water	Biodiversity	Emissions
		2	4	2
 Medium	- Initial Setup: IoT sensors, software, and field monitoring tools can have high upfront costs. - Farmers may lack the knowledge, time or confidence to utilise advanced tools effectively. - Remote farms may face issues with internet connectivity, limiting IoT functionality.	**Materialisation of Benefits = Short-Term (1-2 years)** Adaptation to deliver tangible benefits within a short time frame of 1-2 years. This period reflects the fact that benefits can begin to show within a single growing cycle.		

A high-level roadmap for adaptation measure implementation

Given the multi-factor nature of the analysis (covering impact, cost, co-benefits, barriers), it is challenging to arrive at a conclusive order of implementation prioritisation for the recommended adaptation measures. However, the following groupings and commentary provides an initial steer over immediate, medium and long-term time horizons.

1 - Immediate	High-Impact, low-cost with strong co-benefits - **cover cropping, composting & reduced tillage, IPM & species diversity (companion cropping)**: cost effective measures compared to infrastructure-heavy investments. Provide multiple co-benefits, including improved soil health, water retention, enhanced biodiversity and carbon sequestration. Can be scaled relatively rapidly with financial incentives to support adoption.
2 - Medium	Medium-cost measures with strategic importance - **precision irrigation, rainwater harvesting, plus precision agriculture & IoT monitoring**: moderate to high upfront costs with strong long-term advantages (i.e. water management). Scalable with industry and government support. Advanced tech optimises irrigation and soil health but may be costly and complex for smaller farms.
3 - Long	Higher-cost, challenging measures requiring long-term investment and enablers - **cultivation of drought & heat-tolerant varieties, and drainage infrastructure:** higher initial costs to fund and implement but once proven and established offer long term climate-resilience and mitigation against future yield and quality losses. Offers supply chain security for brewers as global climate risks take hold.

04. Strategic sector recommendations

3keel

BBPA THE VOICE OF BREWERS & PUBS

ZERO CARBON FORUM

Targeted recommendations to build lasting supply chain resilience for the UK brewing sector

The following section outlines the key strategic recommendations aimed at building long-term resilience for barley & hop production and **securing the supply chain for the UK brewing sector.** These recommendations are designed from a sector-wide perspective, recognising that the most effective response to climate risk **requires collective action** across growers, brewers, and policymakers.

Rather than basic isolated interventions, these recommendations reinforce one another—addressing risks through **a combination of on-farm adaptation, supply chain collaboration, and policy engagement**. While some strategies focus on immediate action, others take a longer-term view, such as investment in research, breeding programs, and infrastructure.

We have also highlighted specific policy enablers separately, **recognising the critical role of government and regulatory support** in sustainable adaptation. This includes funding mechanisms, incentives for climate-smart practices, and infrastructure investments that align with broader sustainability goals.

Overview of recommendations for the UK brewing sector

The seven recommendations outlined below are designed to build sector supply chain reliance in the face of mounting climate risks. As shown in the visualisation, the improvement of sourcing traceability underpins the other six recommendations; gaining visibility into the origin of sourced hops and barley is foundational in order to drive upstream action to mitigate risk.

Improve sourcing traceability

- Foster value chain collaboration
- Leverage financial support mechanisms
- Take a landscape approach
- Stimulate market demand & development
- Fund research and development
- Knowledge sharing and demonstration pilots

1. Improve sourcing traceability

Description

At a fundamental level, the UK brewing sector must enhance the traceability of where and how its raw ingredients are produced. Without greater supply chain transparency and traceability, it is difficult to assess climate risks, measure sustainability progress, or ensure that regenerative agricultural practices are being adopted widely & effectively.

Improving sourcing transparency will allow brewers to prioritise sustainable suppliers, support transitioning farmers, and track environmental impacts.

Impact

- Enables identification of vulnerable regions and climate risks before escalation into supply shortages.
- Allows greater influence over implementation and tracking of on-farm measures.

Barriers

- Fragmented supply chains - hops & barley sourcing via multiple intermediaries makes direct visibility challenging.
- Regularly shifting supplier bases.

Enabler

- Existing certification systems: e.g. LEAF Marque, Regenagri, or SAI Platform.
- Growing regulatory demands (e.g. GHG accounting) driving industry-wide adoption of traceability.

Actions

1a: Establish dedicated supply groups or producer pools to significantly enhance collaboration between producers, processors, maltsters, traders, and brewers. These structured alliances would streamline the supply chain, ensuring consistent quality, traceability, and sustainability of raw materials.

1b: Establish improved data gathering mechanisms - develop robust data collection systems to track where and how barley and hops are produced, ensuring full supply chain transparency.

Effort

Medium to High

2. Foster value chain collaboration

Description

To address shared sustainability and climate challenges, the UK brewing sector must foster greater cohesion, collaboration, and co-investment across the entire value chain. This could include:

- Developing shared infrastructure, i.e. on-farm reservoirs and regional climate monitoring networks
- Encouraging regenerative agriculture, using premium pricing and market incentives
- Leveraging brewery by-products (e.g., spent grains, yeast, and hops).

Impact

- Strengthens collective action and resource efficiency, enhancing resilience while supporting sustainability goals.
- Sends a stronger, more unified message to government and suppliers.

Barriers

- Challenges of pre-competitive work in face of competition for % market share and competition law.
- Resource requirement for a coordination function e.g. a secretariat

Enabler

- Existing alliances & partnerships – collaboration with organisations such as SAI Platform, AHDB.
- Regulatory / govt support for sustainability efforts - incentives for sustainable farming.

Actions

2a: Establish a UK brewing sector climate alliance - form a dedicated industry-wide coalition - e.g. via BBPA - including brewers, suppliers, researchers, and farmers, to align sustainability priorities and prevent duplication of efforts.

2b: Promote regenerative agriculture - offer premium pricing, long-term contracts, and incentives for farmers adopting climate-resilient practices.

2c: Launch an annual brewing resilience summit - focused on collaboration, innovation, and climate risk mitigation.

Effort
Medium

3. Leverage financial support mechanisms

Description

Consider the creation of small capital grants, low-interest loans, or cost-sharing programs to help farmers / suppliers invest in critical adaptation measures. The cost of transitioning to a more sustainable future cannot and should not be borne purely by farmers.

Underwriting insurance costs, offering price incentives (i.e. premiums), facilitating access to credit and reimbursing adoption costs (i.e. MRV) could all be critical options.

Impact

- Accelerates adoption of regenerative agriculture across entire sourcing regions.
- Enhances biodiversity & carbon sequestration.

Barriers

- Complexity of multi-stakeholder collaboration.
- Breweries need to commit to multi-year landscape investments.

Enabler

- Industry partnerships – breweries, banks, and policymakers can work together to co-fund adaptation.
- Collective approach to securing UK productivity / sector wide effort.

Actions

3a: Create capital grants and low-interest loans - to help farmers invest in precision irrigation systems etc.

3b: Encourage farmers to adopt regenerative techniques by offering premium pricing for climate-resilient barley and hops

3c: Facilitate access to credit - improve financial accessibility for farmers by partnering with banks or industry funds.

3d: Provide ambitious long-term contracts - ensure supply chain stability by securing multi-year contracts.

Effort
Medium to High

4. Take a landscape approach

Description

The UK brewing sector could leverage existing landscape scale initiatives to drive holistic, large-scale environmental improvements across farming regions that supply barley and hops. By engaging with platforms such as:

Landscape Enterprise Networks (LENs).

A landscape approach would allow brewers to influence wider regional sustainability, rather than affect farm-level change.

Impact

- Accelerates adoption of regenerative agriculture across entire sourcing regions.
- Enhances biodiversity & carbon sequestration.

Barriers

- Complexity of multi-stakeholder collaboration.
- Breweries need to commit to multi-year landscape investments.

Enabler

- Existing frameworks & funding models – i.e. LENs already provide structured mechanisms for investment and implementation.

Actions

4a: Develop a brewing-specific landscape initiative - work with LENs and/or others to establish a tailored programme for hop and barley supply regions, integrating landscape-scale regenerative practices.

4b: Co-fund regional water & soil health - invest in catchment-based water management (e.g., wetland restoration, improved drainage) to reduce flooding, improve irrigation resilience, and enhance soil carbon storage.

Effort
Medium to High

Landscape Enterprise Networks (LENs)

LENs® LANDSCAPE ENTERPRISE NETWORKS

One example of an established initiative that uses a landscape approach to build climate resilience is Landscape Enterprise Networks (LENs).

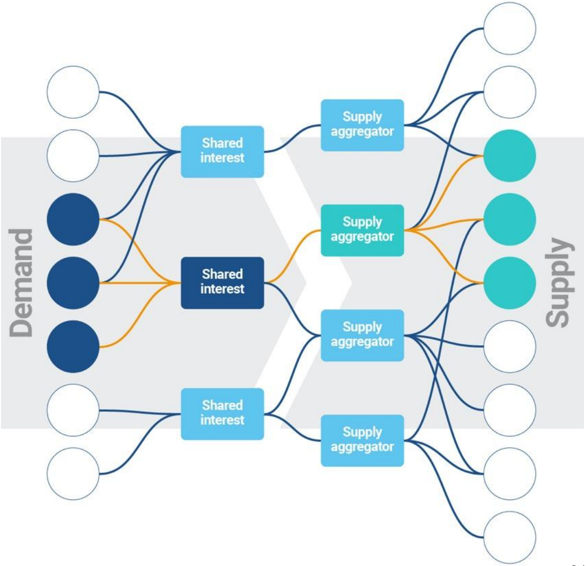
LENs bring together businesses, public bodies, NGOs, farmers and land managers, to finance and implement initiatives to **improve the health, productivity and resilience of landscapes** they all rely on. It does this by **enabling businesses to work together** to influence the quality and performance of the landscapes in which they operate. Typical land management needs LENs addresses are: resilient crop production, mitigating flood risk, improving water quality, reducing GHG emissions, and increased biodiversity.

It provides a process for setting up **networks of regional transactions ('trades') around natured-based solutions** for which there is common interest. Each trade involves a group of buyers (e.g. businesses, natural resource utilities, local authorities) at one end, and a group of land management enterprises (e.g. farmers, land managers) at the other. There are three primary steps in the initial development of a network:

01 Analyse the opportunity

02 Form a collaborative value chain

03 Grow the network



3keel

5. Stimulate market demand & development

Description

One way to drive sustainability in agricultural supply chains would be to stimulate consumer demand for beers brewed with regeneratively grown hops and barley. This could be achieved by integrating a sustainability marque into branding, marketing, and product offerings. The aim being to reinforce the connection between regen ag and beer quality.

A sector-wide approach would help align consumer preferences creating market-driven demand.

Impact

- Drive adoption of regenerative agricultural practices. Strengthen supply chain stability by adding value and securing sustainable ingredient sources.

Barriers

- Designing a sustainability label will require collaboration with certification organisations, and sustainability experts.
- Supply chain verification takes time and can be expensive.

Enabler

- Growing consumer interest in sustainable and ethical products could drive demand for regenerative beers (see Carlsberg and Gipsy Hill).
- Alignment with Net Zero commitments.

Actions

5a: Certification: create or align with a standard that qualifies as regenerative hops and barley, including soil health metrics, biodiversity indicators, and carbon sequestration goals.

5b: Branding: create a distinct, recognisable label or sustainability marque (e.g., "Brewed with Regenerative barley") to be placed on packaging.

Effort
Medium to High

6. Fund research & development

Description

Partner with a greater number of academic institutions and crop genetic programmes, such as those already underway at John Innes Centre (JIC) & Heriot-Watt University, technology providers, and agricultural organisations (e.g. UK Agri-tech Centre) to fast-track innovations specific to the future of the brewery sector.

Support breeding programs for drought- and heat-tolerant barley and hop varieties.

Impact

- Advances technological solutions that address climate risks while ensuring long-term supply chain stability.

Barriers

- R&D requires upfront funding, particularly for long-term projects like developing drought-resistant crop varieties. Time Frame - can be 10-15 years.
- Market hesitancy - in terms of uptake, commercial proof.

Enabler

- Pre-existing Public-Private Partnerships (PPP): Facilitate collaboration between academic institutions, government bodies, and private companies to pool resources and expertise.

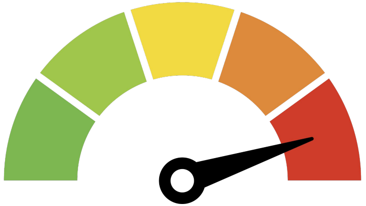
Actions

6a: Co-fund crop-specific breeding programs tailored to UK climate risks to reduce dependence on imported barley and hops.

6b: Launch R&D partnerships between breweries, technology providers, and Defra to reduce upfront innovation costs.

6c: Support demonstration farms to test new technologies under real-world / UK conditions and encourage rapid scaling once proven.

Effort
High



7. Knowledge sharing and demonstration pilots

Description

To drive climate resilience in the brewing supply chain, farmers need access to knowledge, training, and hands-on experience. The UK brewing sector should look to provide greater education and training resources, such as:

- Online resources and data-sharing platforms
- Workshops and field demonstrations on cover cropping etc.
- Pilot farms and demonstration projects that provide real-world examples.

Impact

- Strengthens farmer capacity to implement and sustain climate adaptation measures.
- Encourages adoption of proven techniques by showcasing the tangible benefits.

Barriers

- Farmers may lack awareness or urgency around climate adaptation needs.
- Competing priorities, many farmers are focused on short-term operational pressures over long-term training.

Enabler

- Collaboration between government, academia, and the private sector can pool resources and expertise.

Actions

7a: Develop a centralised training & knowledge platform - Establish a digital resource hub where farmers can access up-to-date insights

7b: Organise pre-competitive on-farm demonstrations & peer-learning workshops.

7c: Establish region-specific pilot farms for barley & hops - partner with research institutions and farmers to create demonstration farms that trial climate adaptation techniques.

Effort
Medium

Key policy enablers to build supply chain resilience

An enabling regulatory environment is crucial if sector action is to be successful. Below we have identified specific government actions which would support the building of resilience in the UK brewing sector's agricultural supply chain:

1. Expand government investment in climate-resilient agriculture

Ask: Increase funding for plant breeding, on-farm infrastructure, and regenerative agriculture through Defra and Innovate UK.

- **a:** Commit to long-term, non-proprietary funding for the development of drought-resistant and heat-tolerant barley and hops, securing the future of UK ingredient supply.
- **b:** Expand grant eligibility for drainage, rainwater harvesting, and precision irrigation by extending the likes of the Farming Equipment and Technology Fund (FETF) to cover these essential adaptation measures.

2. Reform water abstraction and storage regulations

Ask: Simplify planning permissions at local level for on-farm reservoirs and improve flexibility in water abstraction licensing.

- **a:** Introduce fast-track planning approvals for on-farm water storage infrastructure, enabling farms to capture winter water for greater spring and summer drought resilience.
- **b:** Revise water abstraction regulations to ensure agriculture and food production are prioritised during droughts.

3. Scale up public-private collaboration in R&D and sustainability

Ask: Support deeper collaboration between brewers, farmers, and government through targeted investment and incentives.

- **a:** Collaborate on co-investment schemes where brewers contribute to on-farm sustainability projects, with targeted / matched government funding.
- **b:** Increase research funding through Defra and Innovate UK to accelerate innovation in soil health, water efficiency, and pest resilience in barley and hop production.

Key policy enablers to build supply chain resilience - cont'd

4. Acknowledge the brewing sector's existing climate commitments & regulatory needs

Ask: Recognise the brewing sector's leadership on sustainability and provide targeted regulatory support where needed.

- **a:** Work with the sector to build on sustainability progress through initiatives like the BBPA's Brewing Green, while identifying gaps where government intervention is necessary.
- **b:** Ensure UK regulatory policies do not disadvantage sustainable domestic agriculture, while imported ingredients are held to the same environmental standards.

5. Expand financial mechanisms to support farm-level adaptation

Ask: Establish additional capital grants (as part of ELMs) or cost-sharing schemes, and low-interest loans to help farmers invest in adaptation measures.

- **a:** Integrate greater financial support for drainage, irrigation, and regenerative agriculture into existing ELMs schemes, including Countryside Stewardship (CS) and the Sustainable Farming Incentive (SFI).
- **b:** Expand existing support for agroecological transition measures e.g. cover cropping, reduced tillage & composting.

6. Enhance UK sourcing visibility & provide leadership on supply chain transparency

Ask: Support the development of new government sanctioned digital supply chain tracking systems to enhance reporting and accountability.

- **a:** Invest in the creation of industry-wide sustainability reporting platforms, allowing brewers to track and verify sustainability claims across supply chains.
- **b:** Support the industry to invest in blockchain and satellite monitoring technologies to enable traceability of regenerative practices in brewing ingredients.

05. Conclusion

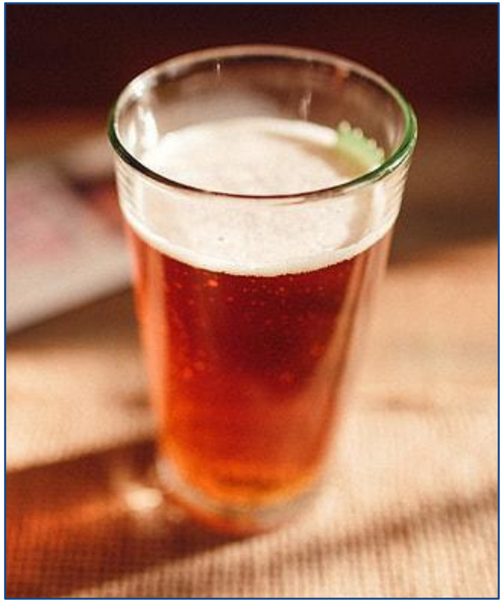
Supply chain resilience relies upon urgent collective action from UK brewing sector

The UK brewing sector's key barley and hop-sourcing regions, both domestically and overseas, are **already facing material climate risks** such as drought, extreme heat, and flooding. As these advance, they pose an existential threat to the industry.

Current projections show impacts from both chronic and acute risks growing increasingly severe in the coming decades. Overall, the UK may ultimately remain more viable for agricultural production than parts of continental Europe and the US. However, supply constraints may force prioritisation of use of barley for food over brewing. Additionally, as specific hop varieties grown in concentrated locations are threatened brewers may be forced to adjust product portfolios.

It is therefore **crucial that UK brewers take urgent near-term action to build resilience** against such risks. Targeted on-farm adaptation measures must be implemented urgently to protect hop and barley growing, and the brewing sector has a direct responsibility to drive coordinated investment in these measures.

By taking a unified approach to improve traceability, channel adaptation financing to farmers, and engage with policymakers, the UK brewing sector can ensure long-term supply chain resilience is secured.



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A1: UK sourcing assessment method & risk maps

Severity - vulnerability assessment

Aims of the assessment

To identify which crops, regions, and climate risks are most material to BBPA members. This will enable us to focus the impact and adaptation assessment on the most salient areas.

Vulnerability definition

Vulnerability refers to the **susceptibility of the crop to the given climate risk** in terms of ability to cope, recover, and adapt. Vulnerability is related to severity and likelihood — the **more vulnerable the crop is to the risk, the higher the impact is if the risk magnifies**.

Severity definition

Severity measures the magnitude of a given risk within a region – a **higher severity score implies higher intensity or extent for a particular risk**. For example, a region that is projected to experience extreme water stress, e.g. the South East of England, will have a high severity score for that risk.

Caveats on interpretation:

- The severity scores in the report focus on 2080 to simplify communication. The major trends will be similar across the two time periods.
- These analytical tools are only one part of the assessment, a large amount of qualitative research also informs the impact and adaptation assessment, including interviews with hop growers and barley maltsters.

Hops: Vulnerability ratings

A qualitative assessment of the degree of hop's vulnerability to 3 climate risks was carried out based on literature research, climate events to date, and 3Keel's previous work with brewers. Ratings are shown below:

Drought = 4

+ Generally, relatively tolerant to drought compared to other crops.
+ Established hop plants have a deep root system, which increases drought resilience.
- Newly planted hop vines are more susceptible to drought.
- Drought-weakened hops are more susceptible to pest and disease.

High temperature = 6

+ Generally, hops are a moderately heat tolerant crop.
+ Hop production region may shift northwards, benefitting the UK market in comparison to EU competitors.
- Long term increases in spring average temperature can have an adverse effects on growth rates.
- Increased temperatures in late summer can have a large impact on taste profile.

Flooding = 9

- Flooding during the growing season is particularly damaging. Note, hops can withstand more flooding during winter.
- Multi-year maturation times for hops mean that permanent damage from extreme flood event will take years to recover.

Risk	hops vulnerability
Drought	4
High temperatures	6
Flooding	9

10 = Highly vulnerable

1 = Highly resilient

Barley: Vulnerability ratings

A qualitative assessment of the degree of barley's vulnerability to 3 climate risks was carried out based on on literature research, climate events to date, and 3Keel's previous work with brewers. Ratings are shown below:

Drought = 5

+ Generally, relatively tolerant to drought compared to other cereals.
+ Better able to maintain yield under moderate drought stress due to shorter growing cycle.
+ Breeding of drought tolerant varieties underway , due to barley's importance as a staple crop.
- Particularly vulnerable to drought during flowering and grain filling periods.

High temperature = 6

+ Generally, moderately heat tolerant compared to other cereals.
+ Some evidence that increased temperatures will increase barley yields at northern latitudes.
- Vulnerable to temperatures above ~30°C+ when flowering and grain filling, otherwise can withstand up to 35°C+.

Flooding = 8

+ barley is comparatively more susceptible to waterlogging and flooding than other cereals.
+ Early-stage flooding e.g. during germination or vegetative growth is less detrimental than critical growth stages of flowering and grain filling, however, can still be severe if prolonged.
- Particularly vulnerable to flooding in regions with heavy clay soils, compared to faster draining sandy/loamy soils.

Risk	**barley vulnerability**
Drought	5
High temperatures	6
Flooding	8

10 = Highly vulnerable

1 = Highly resilient

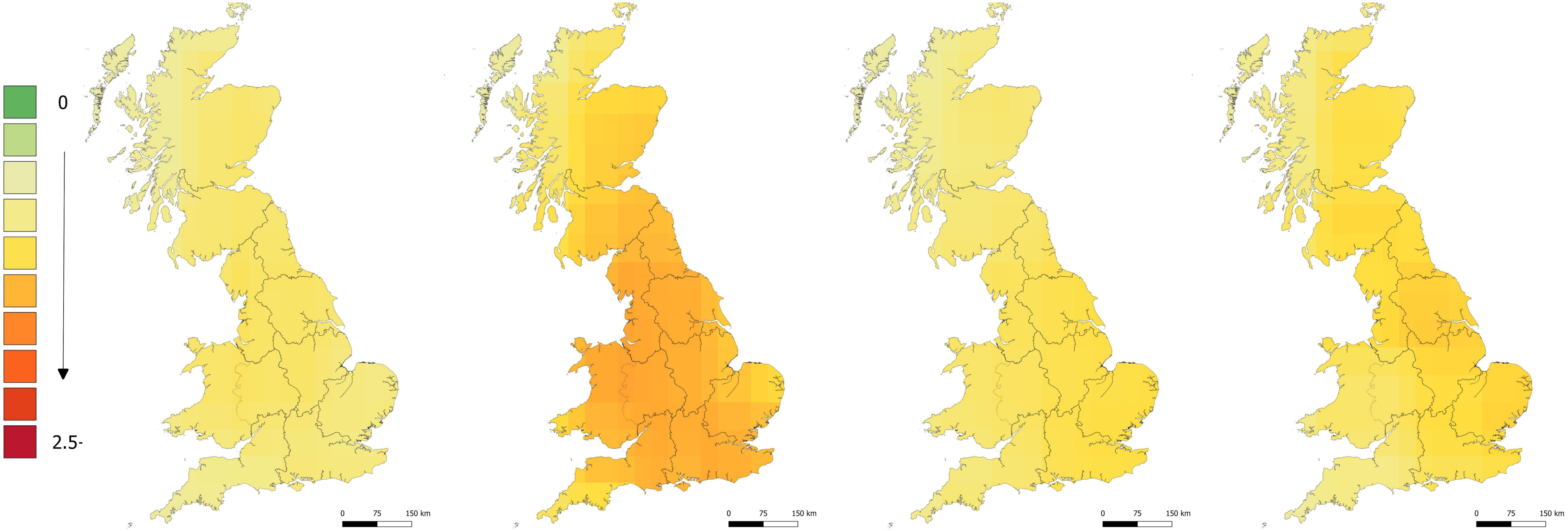
Temperature increase: 2040

Spring
Mar-Apr-May

Summer
Jun-Jul-Aug

Autumn
Sep-Oct-Nov

Winter
Dec-Jan-Feb



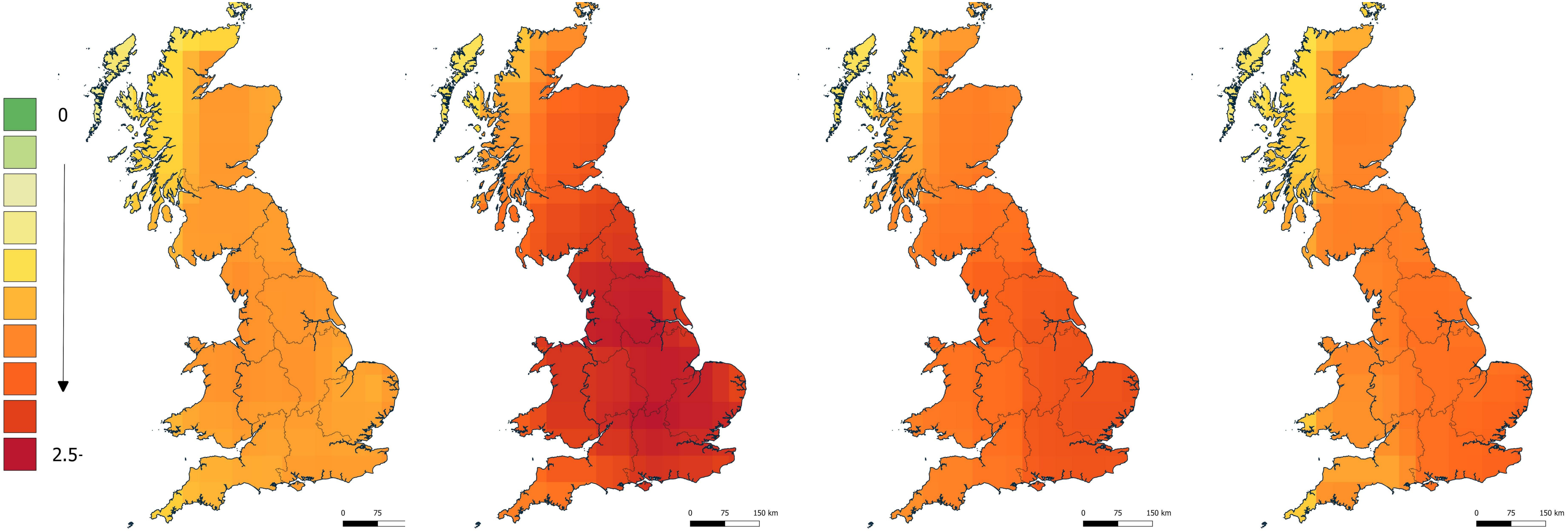
Temperature increase: 2080

Spring
Mar-Apr-May

Summer
Jun-Jul-Aug

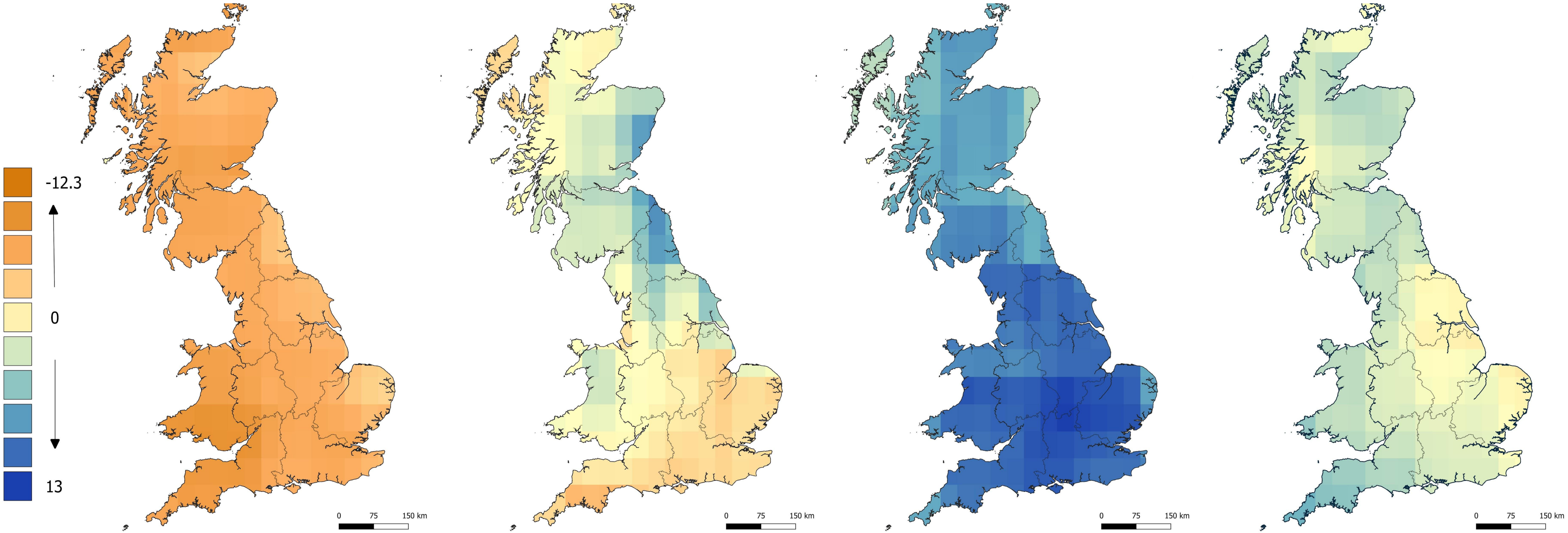
Autumn
Sep-Oct-Nov

Winter
Dec-Jan-Feb

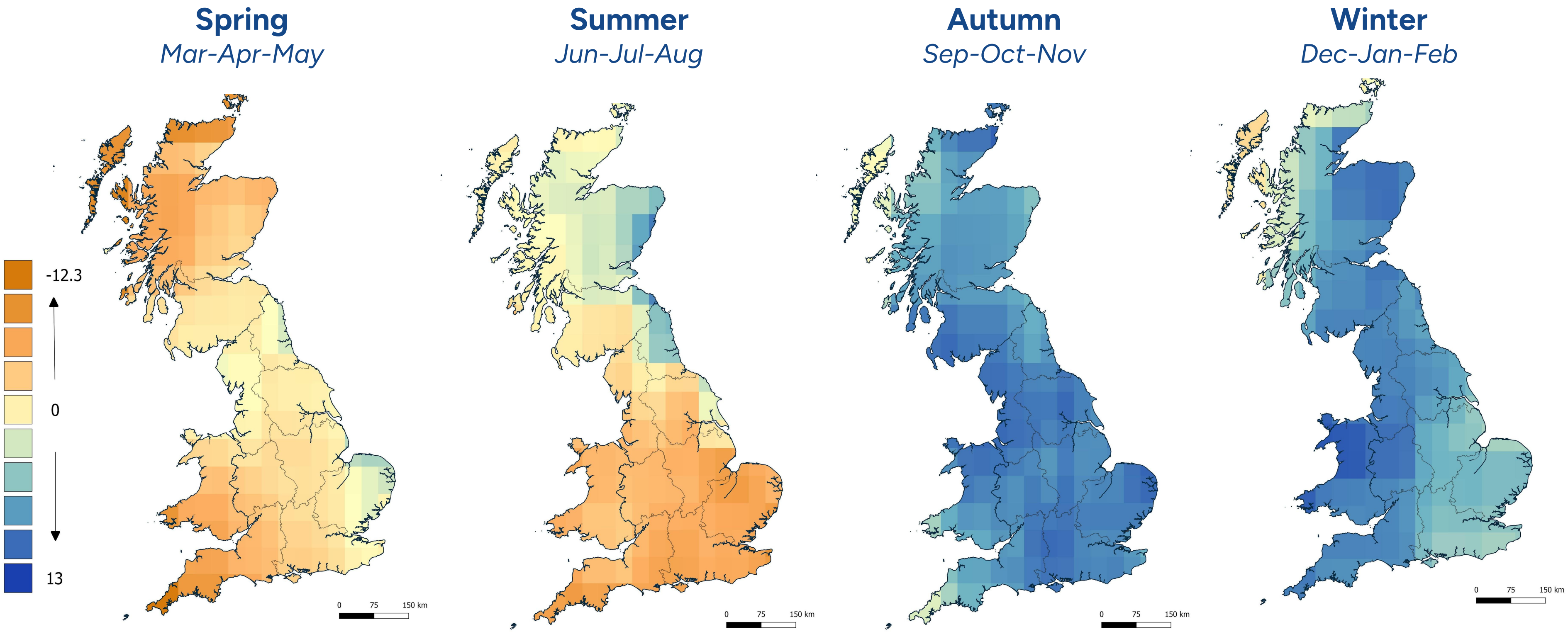


Rainfall: 2040

Spring *Mar-Apr-May* | **Summer** *Jun-Jul-Aug* | **Autumn** *Sep-Oct-Nov* | **Winter** *Dec-Jan-Feb*



Rainfall: 2080



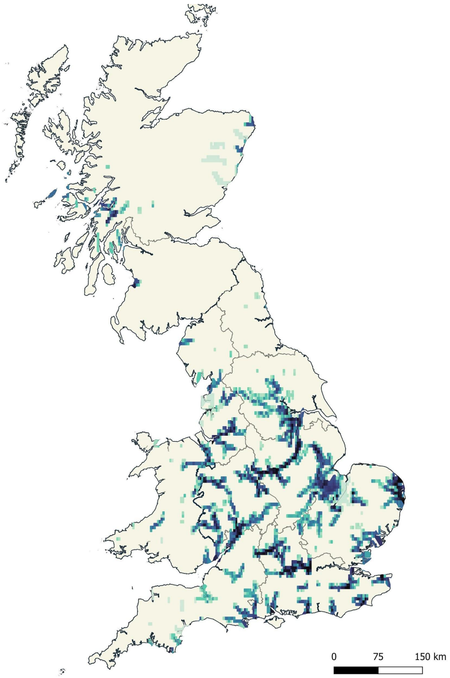
Flooding

Flooding exposure (% of land)

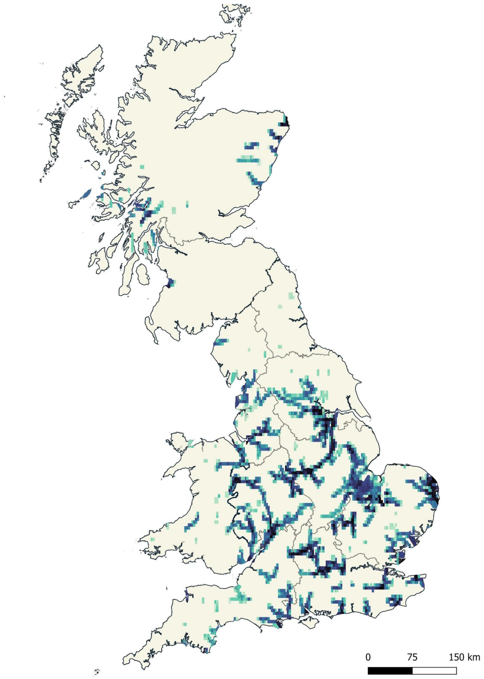
-0.39

4.5+

2040
Annual



2080
Annual



10 point scale per risk

Score	Rainfall	Temperature	Flooding
Units	% change over time	increase in degrees celsius over time	% change of land area at risk of flooding
1	-12.3 - -9.8	0 - 0.25	-0.39 - 0.1
2	-9.8 - -7.2	0.25 - 0.5	0.1 - 0.6
3	-7.2 - -4.7	0.5 - 0.75	0.6 - 1.09
4	-4.7 - -2.2	0.75 - 1	1.09 - 1.59
5	-2.2 - 0.4	1 - 1.25	1.59 - 2.08
6	0.4 - 2.9	1.25 - 1.5	2.08 - 2.58
7	2.9 - 5.4	1.5 - 1.75	2.58 - 3.07
8	5.8 - 8	1.75 - 2	3.07 - 3.57
9	8 - 10.5	2 - 2.25	3.57 - 4.07
10	10.5 - 13	2.25 - 2.5	4.07 - 4.56

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