English Wine – Increased Production and Exports

Summary

Key policy messages

This case study is an example of how climate change could have a positive impact on an outcome. It looks at pledges by the Government and the wine industry to increase vineyards from 2000 to 3000 hectares by 2020 and to increase domestic wine production to reach 10 million bottles/year. This case study has also considered possible longer-term goals of 20 million bottles/yr by 2030 and 40 million bottles/yr by 2040. Climate change is projected to increase the achievability of these outcomes, improving the agro-climatic conditions and productivity of English wine. By 2040, climate change could mean that England has become an 'intermediate climate' wine area, with higher wine suitability than today. After 2040, there are likely to be different future wine climates in England depending on whether a 2 and 4°C pathway arises. However, wine is also affected by climate variability and extremes, which along with a potential decline in summer precipitation, could have negative impacts. Furthermore, decisions to expand wine production in the next decade involve long life-times and lock-in, because of land-use change and high capital investment, therefore, upcoming decisions on new plantations / varieties need to consider the future climate. The study has also assessed potential adaptation options. In terms of opportunities, the immediate priority is for the Government to create the enabling environment for the wine industry to take advantage of enhanced suitability. There is also a need to increase the uptake of no and low-regret options to address variability, noting there are practices from current wine growing countries that have good rates of return. Finally, given the changes in wine suitability, plus the risks of changing pests and diseases, there is an early priority to enhance monitoring, information and surveillance, and to provide iterative support over time to the wine sector. The key conclusion is that climate change could help increase the achievability of production outcomes, but only if Government creates the enabling environment. Such action would lead to large economic benefits for the English wine sector, with a high benefit to cost ratio.

What is the policy objective and outcome?

The 2nd National Adaptation Programme (Defra, 2018) does highlight the potential for profitable and productive agriculture and forestry sectors to take the opportunities from climate change, although it does not explicitly identify wine.

This outcome is focused on one such opportunity, for English wine production and exports. There is no specific policy objective for English wine production. However, in 2016, the English Wine Round Table with the Wine and Spirit Trade Association and Defra made pledges to increase the hectares of vineyards from 2,000 to 3,000 ha by 2020, and to increase wine production to reach 10 million bottles in 2020, with the ambition that 25% of this would be exported, generating £30 million in export revenues (WSTA, 2016). Looking further, Wines of Great Britain has estimated that in 2040 annual production could reach 40 million bottles (WGB, 2016). This case study focuses on the potential influence of climate change on these outcomes. It is different to others in this study, as it investigates how climate change could make possible these future outcomes easier to achieve, and what action is needed to ensure these opportunities are realised.

This case study uses the 2020 goal (10 million bottles/year) as a current target, with an interim outcome of 20 million bottles/year by 2030, on a pathway to 40 million bottles/year by 2040. An outline theory of change / logic model has been developed for this, although it is noted that this is a productivity outcome, while the success of the English wine sector will be due to quality as well as quantity. The UK is currently a major wine importer (of the wine consumed, only 0.1% is produced domestically, HoC, 2016), thus increased production of wine will have positive trade effects, whether this results in increased exports, or reduced imports. It is also noted that the impact of Brexit will clearly have large consequences for the sector, but as these are extremely difficult to predict currently, we have not considered the impact of Brexit on the outcome.

How does climate change affect the outcome, in a 2 vs 4°C pathway?

The current climate has a major influence on wine suitability, as well as productivity and quality (Irimia, 2012; Jones, 2015). The impact of climate change on wine production in England is generally reported to be positive (Nesbitt et al., 2016; Hannah et al., 2013), because of the shift to a more favourable (warmer) climate for grape growing, therefore making the outcome above potentially easier to achieve, or leading to higher production (exceeding the outcome). The first step has been to assess the effect of climate change on the outcome under a 2 and 4°C world. There are some literature studies on climate change and wine in England. These are generally positive, for example, they report that 2°C of warming is likely to change England into an 'intermediate climate' wine region, i.e. a major positive outcome compared to the current climate (Georgeson and Maslin, 2017). Extrapolating further, 4°C of warming could make England into a 'warm' wine region. Therefore, while climate change could open a range of opportunities for growing different varieties of grapes which are currently cultivated in Europe, the level of warming will affect the type of opportunity.

This study has reviewed the literature to understand the potential effects of climate change on English wine, considering the new UK Climate Projections 2018 (UKCP18, Lowe et al., 2018). The latter reports an increased chance of milder, wetter winters and hotter, drier summers along with (generally) an increase in the frequency and intensity of extremes. Rising temperatures will increase average growing season temperatures, and have positive effects on English wine production (and probably quality) (Georgeson and Maslin, 2017). However, wine is also affected by temperature variability and extremes, notably from the frequency and intensity of mid-winter low temperature, late spring frosts, and the influence of excessive summer heat (Fraga et al. 2012; Jones, 2015; Mosedale et al. 2015; Nesbitt et al., 2016). The effects of climate change on these events (frequency and intensity) is more uncertain, and is not necessarily positive. There will also be changes from the amount and timing of rainfall and water availability. These may be positive, but could also include some downside risks from too much, or too little rainfall: these depend strongly on the timing of rainfall during the growing cycle. There are also possible changes in the range and prevalence of pests and diseases, Finally, CO_2 concentration levels from climate change will also have an influence on wine productivity and quality, although these effects are complicated (Fraga et al., 2012; Schultz, 2010; Wramneby et al. 2010). Therefore, while there is support for a positive effect of climate change on English wine (and the outcomes above), other changes could have negative impacts. As an example, higher yielding years might involve warm springs and autumns and the absence of frosts at critical times, while low yielding years might involve wet and cold weather during flowering, wet and cold growing seasons, and/or spring frosts. It is stressed that climate change will also have impacts on wine growing regions in Europe, and for many of these areas there are large projected impacts from climate change (Hannah et al., 2013): this will also have important implications for English wine (on both the supply side and in terms of comparative advantage, as well as in terms of demand for wines and prices).

What are the economic costs of climate change, i.e. the effect on the outcome?

The case study has quantified, in monetary terms, the possible effects of climate change on the outcome. We have found no available studies that have assessed the economic benefits of climate change on wine production in England, and there are only a few studies on the estimated changes in productivity. To explore this area, the case study has therefore undertaken some sensitivity analysis. The starting point is to look at the economic value of achieving the baseline outcome. Using the retail value of the bottles produced – 10 million bottles in 2020 would be worth between £57.9 million and £200 million (for average and high value bottles). An increase to 20 million bottles in 2030 would be associated with a retail value (current prices) of between £116 million and £500 million, and 40 million bottles in 2040 at between £231 m and £1 billion (average and high value bottles respectively). This does not include the export revenues, nor the wider benefits to the economy (duties, VAT, income taxes and employment). However, it is noted that the short-term production levels, the 2020 goal, will be very challenging to achieve as it would require increasing production above current levels (approximately 4 - 5 million bottles) significantly. The achievement of the 2030 and 2040 targets is considered more feasible, requiring an annual (CAGR) 7% increase in bottle production.

The next step is look at 1) how climate change might make the outcome more easily achievable or increase production above the target and 2) the potential risks of climate variability on the outcome. The study has undertaken 'what-if' assessments of the potential financial benefits. Current production in English vineyards is much lower than in Europe - climate is a major factor in this (Nesbitt et al., 2016), though not the only reason.

The case study has undertaken a sensitivity analysis. This assumes that climate change leads to a 10% to 25% increase in production (due to climate change) above the 2030 target, i.e. an additional 2 to 5 million bottles in the year 2030. This would have an annual retail value of between £10.8 million to £50 million (10%) and 26.95 million up to £100 million (25%), with the range reflecting average and high value bottles prices. Similarly, a 10% increase above the 2040 target (4 million bottles in the year 2040) would translate to additional revenues worth between £21.6 million and £80 million in 2040 (current prices). Finally, a 25% increase would lead to benefits of between £53.9million and £200 million, and a 50% increase, between £107.8 million and £400 million in 2040. These would increase gradually from current levels, with production increasing year by year on average (noting high annual production variability). The cumulative financial benefits (up to 2040) from climate change could therefore be very large. There is also a further benefit if climate change impacts on wine growing areas in other countries negatively (as projected), creating increased export opportunities for England.

However, there is also the potential for downside risks to increase under climate change in England. As set out above, increased climate variability can have negative impacts on wine production and quality, and could offset some of the benefits resulting from a warmer climate, although there is insufficient information to estimate how important these changes might be. Furthermore, there are a number of threshold effects: while there is likely to be a fall in lower temperature threshold levels for wine growing, possible threshold risks are identified around water availability, and the temperature suitability ranges (and heat limits) for some current colder temperature wines.

Finally, it is also highlighted that the expansion of cultivated area for wine (new planting) involves long life-times and considerable lock-in, because it involves land-use change and high capital investment. The payback period on wine is longer than for many other agricultural crops, because of the time to mature. This means that early decisions on new expansion areas in the short- and medium term need to consider the medium and even longer-term climate.

What are the potential adaptation options to address these impacts?

The case study has reviewed the existing activities for mainstreaming climate change in the sector. There is an active programme of support to help the wine industry develop opportunities, but the review here has not found a strong climate component to current activities. The case study has therefore investigated further adaptation options that could be introduced to seize the opportunity presented by a warming climate, as well as to reduce the risks associated with possible climate variability.

Adaptation options have been identified and prioritised to identify early options (i.e. for the next five years or so). In terms of the opportunities from climate change, the immediate focus is for the Government to provide the enabling environment for the wine industry to take advantage of the positive changes in suitability and productivity. In 2016, Defra pledged to gather and make available information on soil types, water resources, and infrastructure networks to identify the best areas of land for production; and the Government has identified 75,000 acres across the country suitable for sparkling wine production. That is the equivalent of the Champagne region. However, work on this is still at a very early stage, and further work is needed to expand this analysis to take account of climate change. This is particularly important given the lock-in involved with the expansion of wine production areas, i.e. for wine investment decisions in the next decade.

In terms of the risks of climate change, climate variability already affects the English wine sector. Enhanced adaptation to address current climate variability would be a no- or low-regret response. Winegrowers already have to address these risks, and adapting to variable conditions is a part of good viticulture practice, but the benefits of enhanced measures is highlighted. There are many lessons that can be drawn from other countries that already experience higher variability (including extremes that would be new for the UK, such as heat). The case study has reviewed some of these options, drawing lessons from existing practice in France (e.g. Neethling et al. (2014): this provides potential options for adoption in England, including for managing water deficits.

In terms of early actions to address long-term change, an enhanced focus on monitoring, information and surveillance is highlighted, for both climate as well as pests and diseases. There is a clear role for Government to support these early actions, to address existing information barriers and create an enabling environment for the private sector (for opportunities and risks from a changing climate).

What are the benefits and potential costs of adaptation?

Finally, the study has undertaken a high-level analysis of the potential costs and benefits of additional early adaptation. This indicates that under a scenario where wine growers were able to realise the benefits of climate change due to better information (and appropriate response), and at the same time introduce adaptation measures to address potential variability risks, there would be very large economic benefits (£0.6 billion present value by 2040, around $70mpv/year), and a high benefit to cost ratio.

Step 1: What is the policy objective and outcome?

The 2nd National Adaptation Programme (Defra, 2018) does highlight the potential for profitable and productive agriculture and forestry sectors to take the opportunities from climate change, although it does not explicitly identify wine. This outcome is focused on one such example of this, for English wine production and exports. The outcome is different to others in the study, in that climate change could generate opportunities, and thus make the outcome easier to achieve.

The first outcome is focused on an objective and related outcome to increase English wine production. There is a second related outcome on increasing English wine exports. There is no specific Government policy objective for English wine production, however, following the first wine roundtable with the Wine and Spirit Trade Associations (WSTA), Defra in 2016 pledged to support[1]:

- An ambition to grow the area of planted vineyards from 2000 hectares to 3000 hectares by 2020;
- An increase in production up to 10 million bottles by 2020;
- An ambition that 25% of this would be exported, representing a 10-fold increase in wine exports, from 250,000 bottles to 2.5 million bottles by 2020. In terms of value, this would be an export increase from £3.2 million to over £30 million by 2020;
- Access to new data on soil types, water resources, and infrastructure networks to identify the best areas of land are for production.

These targets are backed by the Government's Great British Food Unit, launched in 2016 to support British companies to export overseas. The Government has also identified an additional 75,000 acres across the country suitable for sparkling wine (House of Commons, 2016).

Defra reports that annual production in 2015/2016 was 5 million bottles. In 2017, HMRC reported that 3.86 million bottles were produced and released for sale in the UK, a 64% increase compared to 2016 (2.36 million bottles were released). This compares to just 1.34 million bottles released in the year 2000[2]. While English wine production is increasing, there are high levels of annual variability (as with all wine producing areas), which are largely weather related (Nesbitt et al., 2016). The increase from current levels to the 2020 target (10m) therefore involves a large increase in production, making this target very challenging. ADAS reports that of the 2,289ha estimated area planted with vineyards in 2018, 87% was in production, with the remainder mainly comprising of newly planted crops. This means there is some scope for additional production capacity at current levels. Looking further ahead, Wines of Great Britain (WineGB), the national organisation for grape growers and winemakers, estimated that in 2040 annual production could reach 40 million bottles, with a retail value of £0.5 to £1 billion[3]. This would translate in a target of 20 million bottles produced in 2030[4].

This analysis therefore starts with the 2020 goal (10m bottles) as a short-term goal (assuming this is met even if very challenging), as well as an interim goal of 20 million bottles by 2030, on a pathway to 40 million bottles by 2040. It is noted that this is a productivity outcome. However, the value of wine is largely a factor of quality, i.e. it is the combination of quality and volume that determines success.

At the same time, it is highlighted the UK is a major importer of wine (one of the world's largest markets). Demand for wine in the UK increased rapidly in the 1990s and early 2000s. It peaked in 2007 at 13.7 million hectolitres, but has declined slightly since then. In 2015, 12.8 million hectolitres of wine

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[1] Press Release, https://www.gov.uk/government/news/uk-wine-industry-pledges-10-fold-increase-in-exports.
[2] WSTA website, https://www.wsta.co.uk/press/904-2017-was-a-record-breaking-year-for-uk-wine-releases
[3] WineGB estimated a value of £1 billion, but this is based on a comparison between GB and Oregon and assumes high value production (£25/bottle). See https://www.winegb.co.uk/wp-content/uploads/2018/06/WineGB-Industry-Report-April-2018.pdf. We consider this a plausible upper level, but include a lower central estimate of half this value.
[4] The 2030 target is calculated by applying a compound annual growth rate (CAGR) of 7.2% (necessary to reach the 2040 target) to the 2020 target.

were consumed in the UK, but only 18,000 hectolitres, or 0.1% of this, was produced in the UK (House of Commons, 2016). In that year, wine imports totaled £2.9 billion compared to exports worth £ 441 million, resulting in a wine trade balance of - £2.4 billion. Increasing production in the next two decades could help the UK close the trade balance by substituting foreign wines with UK wines, whether through increased exports, or lower imports.

The case study has developed an illustrative **Logic Model** in relation to the goals above.

ACTIVITIES
Creating the enabling environment to support the wine industry to increase production and potentially exports

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OUTPUTS
UK wine makers have access to new data on soil types, water resources, and infrastructure networks to identify the best areas for production.
UK wine makers benefit from agricultural and trade policies that support production and exports.

↓

OUTCOMES
The wine industry produces increased volumes of quality wines (and potentially increases exports)

↓

- Planted vineyards grow from 2000 hectares to 3000 hectares by 2020
- 10 million bottles produced in 2020 (£ 250 million) and 20 million in 2030 (£ 500 million).
- 25% of wine produced is exported

IMPACT
English wine is an increased share in the global market

Figure 1. Illustrative Logic Model for English Wine Production

However, these opportunities will only be realised (fully) if the English wine industry is aware of these potential opportunities, and furthermore, it is aware of some of the potential negative risks from climate change. The positive outcomes are therefore conditional on information and a clear understanding of all the impacts/risks of climate change on wine production by the industry, and that appropriate adaptation strategies are adopted. While the focus of this study is not to produce specific adaptation outcomes (and an adaptation theory of change), as below.

ACTIVITIES
Creating the enabling environment to support the wine industry to take advantage of the opportunities and manage the risk presented by climate change

↓

OUTPUTS
Winemakers understand climate change risks and opportunities and undertake appropriate measures to take advantage/manage risks

Figure 2. Illustrative Logic Model for Adaptation for English Wine Production

Of course, this import-export balance will be influenced by Brexit. Anderson and Wittwer (2017), estimated that the impact of the UK leaving the Customs Union would result in possible tariff changes, but would also reduce UK incomes and devalue the pound: they estimated that for consumers in the UK, the price of wine in 2025 is likely to be 22% higher (in £) than it would be without Brexit. As a result, they assume that the volume of UK wine consumption would be 28% lower, and the value of UK imports 27% lower. At the time of writing, it is extremely challenging to predict future income and export prospects. For this case study, therefore, we have not considered the effects of Brexit, though we acknowledge this is likely to have potentially important effects.

Roles and responsibilities in the outcome delivery

The Department for Environment, Food and Rural Affairs (Defra) is the lead UK Department and the appointed enforcement agency for wine regulation. However, this role sits within a strong European enforcement regime. Currently, European Council and Commission Wine Regulations apply in every EU Member State and include the whole wine value chain from the harvesting of grapes to the sale of wine to the final consumer. EU Regulations contain provisions on: market intervention, rules concerning marketing and production, protected designations of origin and protected geographical indications, trade with third countries, and competition rules.

How does climate change affect the outcome, in a 2 vs 4°C pathway?

The current climate for wine in England

The climate clearly has a major influence on the suitability of areas for wine production, as well as annual wine production and quality (with high levels of inter-annual variability). These effects are complicated, as they involve key variables at different parts of the overall grape production cycle, as shown below.

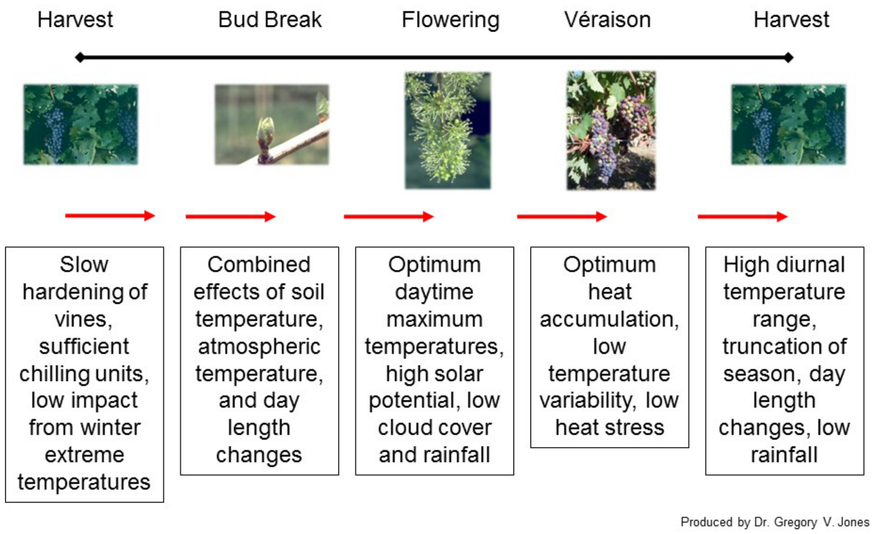

Figure 3 Ideal weather/climate situation for wine production (Jones, 2015)

The average growing season temperature is an important factor affecting the growth, fruiting and chemical composition of grapes, and this is reflected in the general areas of cultivation globally[5]. Areas with an Average Growing Season Temperature (AvGST) of less than 12°C often do not see ripening or the vine is damaged by frost. It is noted that areas with an AvGST above 22°C are also affected detrimentally, and this may be important in climate change affecting the production and quality of

[5] Cultivation is predominantly in the range of 30-50 ° lat. N and 30-40 °lat. S, in zones with an average temperature of the growing season (AvGST, April-October/October-April) of 12 to 22 °C (Jones, 2006).

competitor countries and importers, i.e. it might affect the comparative advantage of current wine producing areas.

Typically, sparkling wines and white table wines are produced in cooler areas with average temperatures in July of 18.1 to 19.7°C; quality white wines in areas with a July average temperature higher than 19.8°C; and quality red wines in areas with an average temperature of July higher than 21°C (Irimia, 2012). The entire temperature range of grape growing climate zones is around 10 °C, although for some grapes, such as Pinot noir, the range is narrower (Santisi, 2011, in Mozell and Thach, 2014).

Over the last two decades, the amount of land under viticulture in the UK has grown significantly. Nesbitt et al. (2016) report that in the last 10-15 years, average temperatures during the grape growing season (April to October) have tended to be above 13^{o}C. This is the minimum temperature that "cool climate" wine grapes need to thrive. Today, there are over 700 individual vineyards in the British Isles ranging from extremely small ones (the smallest only has six vines) to ones of almost 90-ha (222-acres). Together they total around about 2,000-ha (4,942-acres)[6].

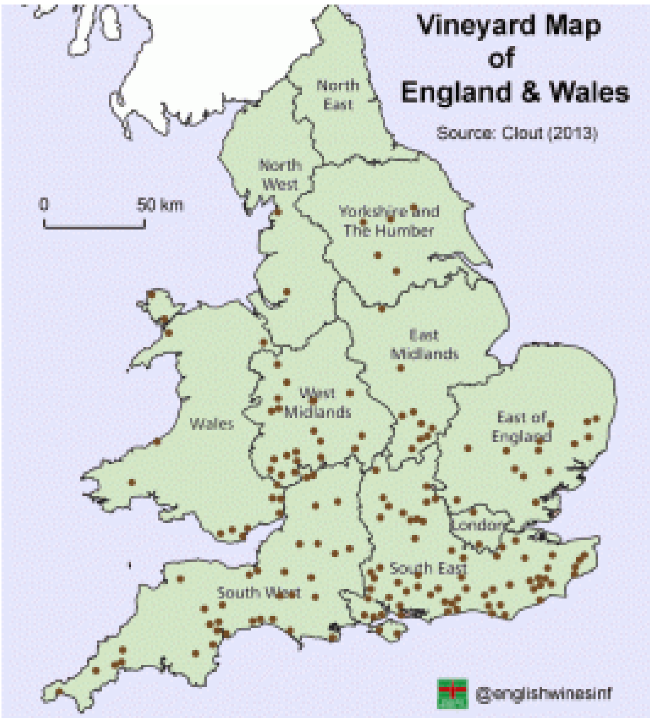

Figure 4 Vineyard map of England and Wales (as of 2013)

In 2004, the UK's most planted cultivar was the hybrid varietal Seyval Blanc (94 ha) followed by the German crossing Reichensteiner (89 ha). Since 2013, Chardonnay has become the UK's most planted cultivar with 327 ha, closely followed by Pinot Noir with 307 ha. The growth of these two cultivars follows the recognition of the very high-quality potential of English sparkling wine category. However, these grapes are more sensitive to climate variability (Nesbitt et al. 2016). Recent vineyard plantings have predominantly occurred in southern England (50–52N) with vineyards in south-east (East and West Sussex, Kent and Surrey) and south-central (Berkshire, Hampshire, the Isle of Wight and Wiltshire) England. However, there are more northern vineyards being planted[7].

[6] Data available at http://www.englishwine.com/vineyards.htm.
[7] See http://www.gbvg.uk/vineyards?province=CMA

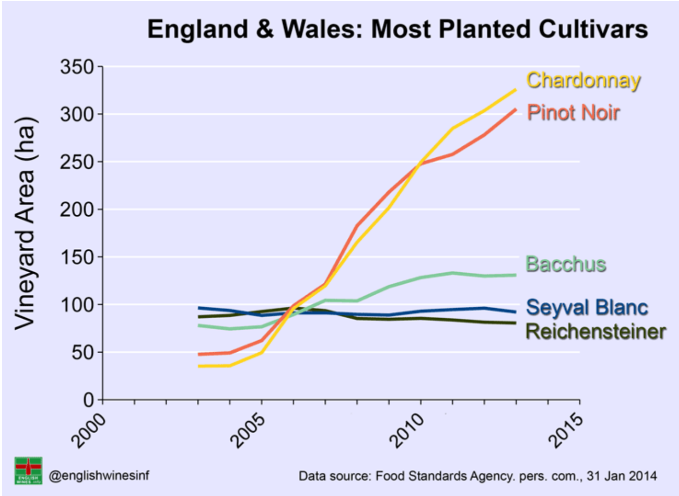

Figure 5 England and Wales most planted cultivars

However, English wine yields are currently very low compared to yields in Champagne (France). Nesbitt et al. (2016) report that in Champagne, yields can be more than 10,000 litres per hectare, but in the UK, in 2015 (a year of high production) they were around 2,100. The research attributes bumper years (1996, 2006 and 2010) to optimum temperatures and weather conditions – warm springs and autumns and the absence of frosts at critical times. Meanwhile low yielding years (1997, 2007, 2008 and 2012) are attributed to wet and cold weather during flowering, wet and cold growing seasons, low levels of sunlight, poor summers and/or spring frosts. The table below (FSA 2017) reports the official production figures to 2015. Wine GB reports that at the end of 2017 there were 2,500 hectares of vineyards in the UK: 1 million vines were planted in 2017 and 1.7 m were planned to be planted in 2018 (Wine GB website).

Table 1 Wine production data (FSA, 2017)

Wine production data		
Year	Hectolitres produced	Hectares in production
2015	38019.65	1839.28
2014	48267.41	1505.73
2013	33,384	1,375
2012	7,751	1,297
2011	22,659	1,208
2010	30,346	1,094.5

Future climate for wine in England
Looking forward, climate change could influence wine production in a number of ways, by influencing the overall suitability of areas for wine production, but also the variables in the figure. The first and most important of these are rising temperature. Increases in average temperature in England, and an

increased growing season (length and temperature) will enhance the potential suitability for growing wine of different varieties.

The UK Climate Projections 2018 (UKCP18) (Lowe et al., 2018; Murphy et al., 2018) reports an overall warmer climate for the UK, alongside an increased chance of milder, wetter winters and hotter, drier summers along with an increase in the frequency and intensity of extremes. The projections for average temperature show a clear warming trend, as below. Under both 2 and 4°C scenarios, England could move from a cool to an intermediate and warm region respectively, potentially widening its range of cultivars and diversifying its domestic wine supply further. Under RCP8.5, these scenarios could materialize by 2060s and 2100 (using the 50th percentile) respectively. The projections of rainfall are more uncertain, and vary on seasonal and regional scale. However, the projections indicate winter precipitation is expected to increase significantly and summer rainfall is expected to decrease significantly. Furthermore, changes in rainfall patterns could affect grapes at key development stages. For example, under a RCP2.6 (~2°C) scenario, by 2050, the increase in winter precipitation is projected (average) to reach up to +25%, with summer rainfall decreasing by over 30% compared to 1981-2000 average (figure 6). Note, however, that the risk of pest and diseases typically also increases with rising temperatures. Furthermore, greater climate variability under a 2 and 4°C degree scenarios could bring about challenges for wine-growers. It is difficult to estimate with certainty what the influence of climate change will be on rainfall, humidity and soil moisture, not least because the projections for these variables has high uncertainty. However, the projected increases in summer rainfall from UKCP18 might suggest possible negative impacts.

	Annual Temperature Change (°C)					Winter Precipitation Change (%)					Summer Precipitation Change (%)				
	5th	10th	50th	90th	95th	5th	10th	50th	90th	95th	5th	10th	50th	90th	95th
RCP2.6	0.2	0.4	1.1	1.9	2.1	-6	-3	8	21	25	-33	-28	-13	2	6
RCP8.5	0.5	0.7	1.5	2.5	2.8	-5	-2	12	29	34	-39	-33	-15	2	7
SRESA1B	0.3	0.5	1.3	2.1	2.3	-8	-5	7	22	26	-34	-30	-13	3	8

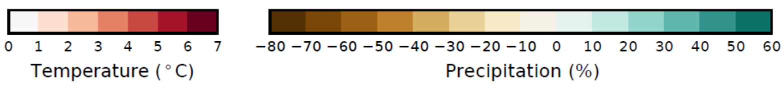

Figure 6 Projected change in temperature and precipitations for the UK region from 1981-2000 to 2041-2060 using the probabilistic projections. (Lowe et al, 2018)

Climate change is projected to have major impacts in the geographic distribution of wine production in the next half century (Hannah et al., 2013 in Mozell and Thach, 2014). This will create winners and losers and depend on the ability of winegrowers to adapt to future changes. The figure below shows the relationships between phenological requirements and temperature for high to premium quality wine production in the world's benchmark regions for each variety. The figure shows that cooler climate varieties such as Pinot Noir, for example, are typically grown in regions that span from cool to lower intermediate climates with growing seasons that range from roughly 14.0-16.0°C (e.g., Northern Oregon or Burgundy). Rising temperatures will affect AvGST, and in turn move the suitability areas and thresholds. This will move some regions outside suitability zones. For example, if a region has an average growing season average temperature of 15°C and the climate warms by 1°C, then that region is climatically more conducive to ripening some varieties, while potentially less for others. If the magnitude of the warming is 2°C or larger, then a region may potentially shift into another climate maturity type (e.g., from intermediate to warm).

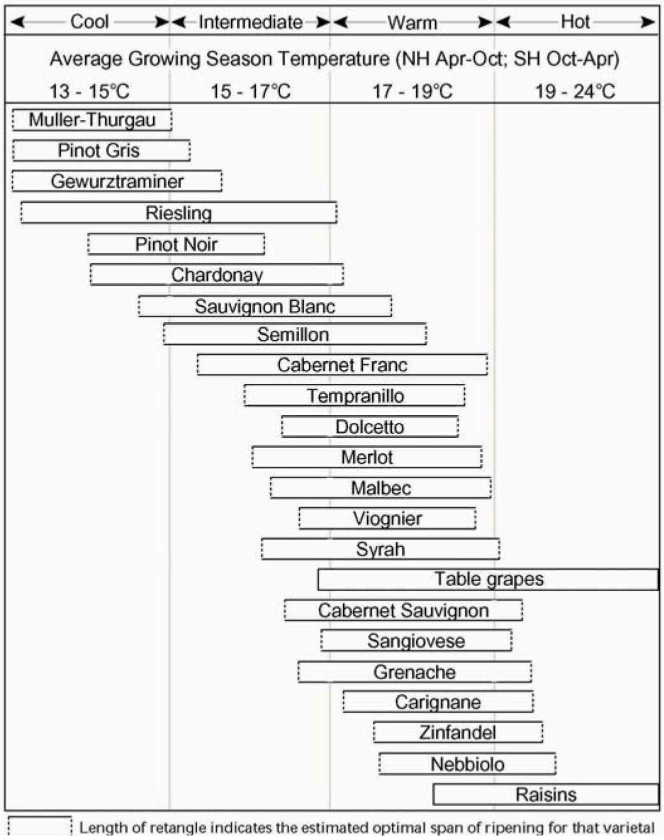

Figure 7 Grapevine Maturity Groupings (Jones, 2006)

Such analysis indicators that England could have a climate that is more suitable for growing wine – as shown by the climate mapping above.

There have been some studies of the potential effects of climate change on wine production in the UK, although none of these have used UKCIP18, which was only released recently (November 2018). These studies show that in the future England could have a comparative advantage in making wine compared to other countries in Europe. Earlier studies, such as Kenny and Harrison (1992) undertook spatial modeling of future climate change impacts on viticulture in Europe and indicated potential shifts and/or expansions in the geography of viticulture regions. They projected parts of southern Europe would become too hot to produce high quality wines and northern regions would become viable. Assessing changes in the Huglin Index[8] of suitability for viticulture in Europe, Stock (2005) reported increases of 100-600 units and broad latitudinal shifts with new areas on the northern fringes becoming viable, changes in varietal suitability in existing regions, and southern regions becoming so hot that overall suitability is challenged. Hannah et al. (2013) also report that suitability is projected to decline in many traditional wine-producing regions (e.g., the Bordeaux and Rhône valley regions in France and Tuscany in Italy) and increase in more northern regions in North America and Europe. At higher latitudes and elevations, areas that are not currently suitable for viticulture are projected to become suitable.

[8] The Huglin index is a bioclimatic heat index for vineyards, in which the temperature sum over the temperature threshold of 10 °C is calculated and then summed for all days from beginning of April to end of September.

The figure below (from Hannah et al, 2013) shows net viticulture suitability change in major wine-producing regions. The box plots show median values and quantiles of change in area suitable for viticulture by 17-member model ensemble for RCP 8.5 (green) and RCP 4.5 (blue). Mediterranean-climate wine-producing regions show declines, whereas New Zealand, western North America, and Northern Europe show substantial increases in area.

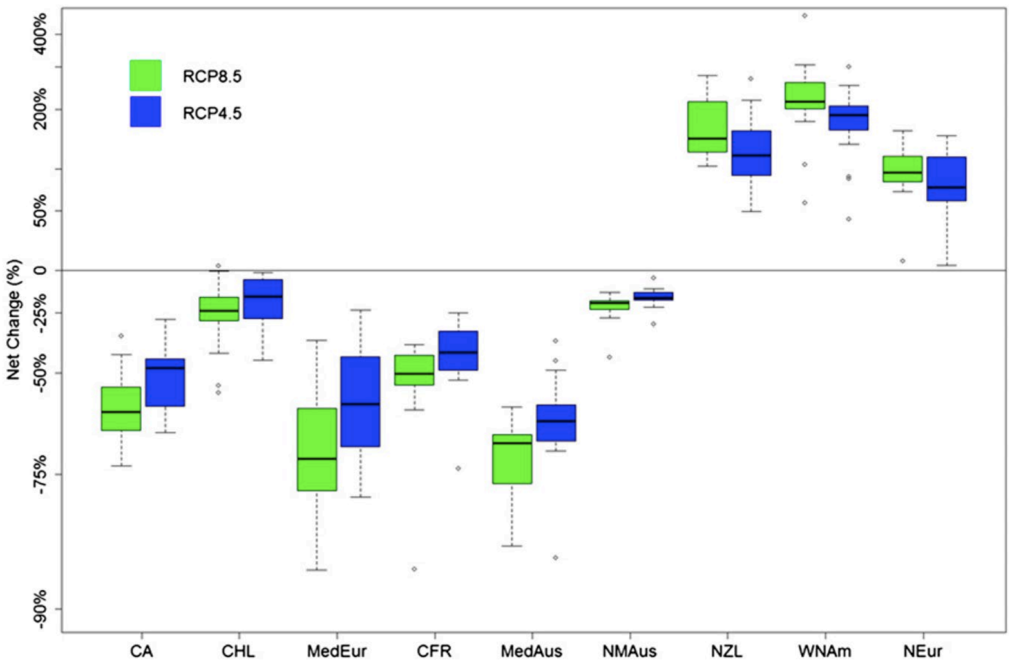

Figure 8 Net changes in area suitable for viticulture by region.

Key CA, California floristic province; CFR, Cape floristic region (South Africa); CHL, Chile; MedAus, Mediterranean-climate Australia; MedEur, Mediterraneanclimate Europe; NEur, Northern Europe; NMAus, non–Mediterranean-climate Australia; NZL, New Zealand; WNAm, western North America (Source: Hannah et al. 2013). Note vertical axis is log-transformed.

This shows that climate change will also have impacts on wine growing regions in Europe, which will also have important implications for English wine, especially as projected impacts are likely for many current wine growing areas on the continent.

Other climate factors

Wine is affected by temperature variability and extremes. Short-term climate variations are key factors influencing seasonal grape and wine production. In the UK, year-on-year vineyard yields are currently highly variable. According to the Vineyards Register published by the Food Standard Agency[9], average national productivity has varied greatly over past years, going from about 19 hectoliters/ha in 2011, to 6 in 2012, up to 24 again in 2013. Yields are susceptible to weather events and conditions at key phenological stages during the growing season, such as at budbreak and flowering.

There a number of variables that are important, but notably the frequency and intensity of mid-winter low temperature (which leads to damage), late spring frosts, and the influence of excessive summer heat. As well as productivity, these can have important impacts on quality. Some of these events affect annual productivity, however, some, such as extreme heat may also permanently damage vine physiology and yield attributes, although the sensitivity varies with variety (Fraga et al. 2012).

[9] https://www.food.gov.uk/business-guidance/uk-vineyard-register.

Grapevines growing under severe heat stress experience a significant decline in productivity, due to stomatal and mesophyll limitations in photosynthesis (Moutinho-Pereira et al. 2004 in Fraga et al. 2012), and can suffer damage (Berry and Bjorkman 1980 in Fraga et al. 2012).

In regions that have a more temperate climate, low temperatures are often a limiting factor for production viability. Jones (2015) identifies that there is a minimum winter temperature that grapevines can withstand. This minimum ranges from -5°C to -20°C, with some cultivars and hybrids being more cold-hardy than others. Temperatures below these thresholds will damage plant tissue by the rupturing of cells, enzyme reductions by dehydration, and the disruption of membrane function. Clearly, in England, winter temperatures and frost damage are a potential limiting factor. During the vegetative growth stage[10] temperatures below 0°C can adversely affect the growth of the vegetative parts of the plant, and hard freezes (<-2.2°C) can reduce the yield significantly. Nearing maturation, early frost or freezes can lead to the rupture of the grapes, which influences disease development and can result in a significant loss of weight in the fruit. Spring frost is a risk to viticulture in many cool-climate regions causing significant crop loss if it occurs after bud-burst (Mosedale et al. 2015) [11].

Frost damage depends on the vine's ability to withstand strong nocturnal cooling (Neethling et al. 2016). For grapevines, the threshold of frost susceptibility rises from −8 °C in pre-budburst to −2 °C in budburst stage (Reynier 2007). Late spring frost can cause severe damage. Looking at viticulture in south-west England, Mosedale, Wilson, and Maclean (2015) examined how key risks to vineyard yields from late spring frost after budbreak and the suitability of weather at flowering, vary under future climate projections[12]. The authors used parameters for the Chardonnay cultivar which is currently the most widely planted grapevine in England. Using growing degree day[13], the projected increase in growing season temperatures under future climate scenarios increased from under 800 GDD to over 1,200 GDD even under the low emissions scenario. This suggests cultivation of a much wider range of cultivars and more reliable and higher quality harvests of wine grapes will be possible in the focal cool-climate region under future conditions. Warmer sites in south-east England currently receive about 850 GDD over a typical growing season which is adequate to permit production of high-quality sparkling and aromatic white wines, but a GDD of about 1,100 is considered necessary in order to permit high quality, reliable harvests of cultivars such as Chardonnay or Pinot Noir.

However, Mosedale et al (2015) showed that risk of late spring frosts increases under many future climate projections due to advancement in the timing of budbreak. Therefore, they advise caution on adopting grapevine varieties more susceptible to frost damage or early budbreak varieties, as an advancement in phenology can potentially increase exposure to frost risk. Estimates of frost risk were highly sensitive to the choice of phenology model, and future frost exposure declined when budbreak was calculated using models that included a winter chill requirement for dormancy break. The results thus indicate that estimates of future crop risk are sensitive not only to future climate projections but also to the choice of phenological model. The lack of robust phenological models is therefore a major limitation to assessing future crop risks and the impacts of climate change on the development of

[10] The period of growth between germination and flowering is known as the vegetative phase of plant development. During the vegetative phase, plants carry out photosynthesis and accumulate resources needed for flowering and reproduction.

[11] Frost and/or freeze occurrence during the spring and fall generally comes in two forms: 1) advection frosts, which occur as cold air masses are brought into a region with the passage of a cold front; and 2) radiation (or ground) frosts, which occur as the ground and the air in the lower layers of the atmosphere (within and just above a grapevine canopy) gives off heat, warming the air in successive layers upward, and the dew point temperature is low enough (Jones, 2015).

[12] One thousand 30-year daily weather sequences were generated for the projected climate conditions for each of three thirty-year time periods (2010–39, 2040–69, 2070–99) under low, medium and high emissions scenarios that respectively correspond to A1FI, A1B and B1 IPCC SRES scenarios (Mosedale et al. 2015).

[13] The most widely used grapevine phenological models are spring warming or growing degree day (GDD) models, which determine the timing of yearly phenophases, such as budbreak, flowering and veraison (when grapes begin to soften and change colour), by the date at which an accumulated measure of daily temperature (or 'forcing') attains a critical value.

cool-climate viticulture in historically marginal climatic regions (Morsedale et al, 2015).

Extreme heat (temperatures greater than 35°C) in either the growing season or the ripening period also negatively impacts grape production by inhibiting the photosynthesis and causing a reduction of color development and anthocyanin production (Jones, 2015).

There will also be effects from the amount and timing of rainfall, humidity, and water availability. In wine making, atmospheric moisture is important in regulating the evaporative demands of the grapevines and the occurrence of fungal diseases. During the growth stages of the grapevine, some of the climatic conditions that can most severely afflict the vines and berries are associated with moisture (Jones, 2015). Further, as reported by Jones (2015), the occurrence of rain during critical growth stages, is necessary but can also lead to impacts. There is a need for sufficient precipitation during the early vegetative stage, as this is beneficial to initial growth; however, during bloom, excessive rainfall can reduce or retard flowering, and during growth it can enhance the likelihood of fungal diseases. During maturation rainfall can increase fungus occurrence and growth, dilute the grape (which reduces the sugar and flavour levels), and limit the yield and quality.

Evidence does not suggest an upper limit on the amount of precipitation needed for optimum grapevine growth and production, but grapevine viability can be limited in hot climates by low rainfall (less than 500 mm), although this can be overcome by irrigation (Jones, 2015). Adequate soil moisture recharge during the spring can drive vine growth and result in more effective bloom and berry set. While some soil moisture during the summer growth period can reduce heat stress, too much soil moisture can drive excess vegetative growth and lead to inadequate ripening and delayed leaf fall, putting the vines at risk of late fall frost/freeze events (Jones, 2015).

Georgeson and Maslin (2017) project that the UK may move from being a marginal, cool-climate region become to an 'intermediate climate' wine region by 2100, however, the authors also highlight climate change could also bring a number of threats to wine growers. They investigated two 'rainfall scenarios' for grape-growing in 2100. Firstly, a 'normal' scenario based on currently acceptable levels of rainfall for UK viticulture[14]; secondly, a 'high threshold' scenario[15] where UK winegrowers are able to adapt to higher rainfall levels. Their model for climate change (temperature and rainfall) projected a further 2.2 degrees of warming by 2100 from the 1981-2005 long-term climate average, and a 5.6% increase in rainfall by 2100. They found that overall, large areas of the UK may be suitable for viticulture in 2100, mostly for white grape varieties and Pinot Noir. However, Britain would not become suitable for warm climate grape varieties such as Sangiovese, Cabernet Sauvignon and Grenache/Garnacha. According to their findings, there is a risk that current wine-producing areas in the south of England may become too wet or too warm for certain cool climate grape varieties, such as Pinot Noir. Only certain areas of the South East of England show the potential to be suitable for intermediate climate red wine grapes such as Merlot and Tempranillo, with potential 'pockets' in Kent, Essex and Norfolk/Cambridgeshire. The East of England appears much more amenable to wine production in 2100, whereas the West of England and Wales will be largely too wet (Gorgeson and Maslin, 2017). The authors concluded that if autumn becomes a lot wetter than currently, this could be dangerous for British viticulture, notwithstanding a warmer climate. September harvests could be one way of counteracting heavy autumn rains, if warmer temperatures in the ripening period allows sufficient fruit maturity in time.

[14] Annual rainfall of below 800mm, and an estimated October rainfall limit of 80mm (the latter is estimated based on current October rainfall averages for the UK and other major wine growing regions).
[15] Annual rainfall of below 1000mm, October rainfall of below 100mm. The 'high threshold scenario' stays within currently acceptable levels of rainfall in other wine regions for both annual and harvest-month rainfall; the harvest-month rainfall in the Rhone valley is over 120mm, for example.

CO_2 concentration levels from climate change will also have an influence on wine productivity and quality. Higher CO_2 concentrations have potential fertilisation benefits. For example, Fraga et al. (2012) reports that enhanced concentrations of CO_2 could have positive impacts on the grapevine development cycle and yield attributes. However, these effects are very complicated for wine because of the potential effects on quality. Schultz (2010) estimated that a rise in CO_2, coupled with an increase in temperature and a shift in relative humidity, might increase biomass, increase sugar (and thus alcohol), and decrease acid levels, all of which will affect grape aroma and flavour. Tate (2001) reports that rising CO_2 will cause faster growth and, therefore, higher sugar concentrations and thicker skin development (thus higher tannin levels) There are also complex indirect effects, for example, higher CO_2 could promote a decrease in plant transpiration, which will tend to over compensate for the increased soil evaporation (Rabbinge et al. 1993), resulting in a reduced evapotranspiration in the future climate (Wramneby et al. 2010)[16]. This are also potential changes in the range and prevalence of pests and diseases. Changes in temperature and humidity may change patterns of insect and insect-borne diseases (range and prevalence), as well as fungal disease.

What are the economic costs of climate change, i.e. the effect on the outcome?

There are no available studies (identified in this work) that has assessed the economic benefits or costs of climate change on wine in England, and there are only a few studies on the estimated changes in productivity and quality. This makes it difficult to estimate the economic effects of climate change with no adaptation, on the outcome. To explore this, the case study has undertaken some sensitivity analysis. This has considered two areas. The first is the potential benefit from a warmer and more suitable climate for wine production (and quality). The second is the more uncertain influence of changes in variability, extremes, water availability, etc. In the context of the outcome, this would mean 1) how much climate change might make this target more achievable or lead to higher production if the target is achieved and 2) the potential risks of climate variability on the outcome. This reflects, respectively, the potential benefit and impact of climate change.

Potential benefits

The starting point for this analysis is to estimate the economic value of achieving the outcome, (which is also the value of foregone production in case the outcome is not achieved). The retail value of the bottles produced – 10 million bottles in 2020 would be worth between £57.9 million and £200 million; and 20 million bottles in 2030 is estimated at between £115.8 million and £500 million (for average and high value bottles). In 2040, 40 million bottles are estimated between £232 million and £1 billion for average and high value bottles respectively. This does not include the export revenues, nor the wider benefits to the economy that this level of production would bring about (duties, VAT, income taxes and employment).

Table 2 Potential Retail Value for Achieving the Outcome for the Possible Targets considered. Range reflects average and higher value bottles.

	2020	**2030**	**2040**
Goals	10 million bottles	20 million bottles	40 million bottles
Economic benefit of achieving the target	£57.9 million to £200 million	£115.8 million to £500 million	£232 million to £1 billion

A rise in annual average temperature of around 2°C degree is likely to change England into an 'intermediate climate' wine region, i.e. a major positive outcome compared to the current climate.

[16] Interestingly, changes to weather patterns and carbon dioxide levels may also affect the development and quality of oak, the primary wood used to age wine in barrel.

Nonetheless, there will be benefits in the short-term. However, there is the potential that greater climate variability will affect English wine growers, potentially lowering productivity level and quality.

The UK goal (the outcome) is to increase production of wine and reach 10 million bottles produced in 2020, and 20 million bottles in 2030, on a possible pathway to 40 million bottles in 2040. The first goal translates into approximately 3,000 hectares of vineyards by 2020, and 10 million bottles – which would equate to 75,000 hectolitres. This is equivalent to 2,500 litres/ha, an increase in UK productivity (although currently varies significantly between years, going from approximately 2,000 litres/ha in 2015 to some 1,400 litres/ha in 2017). However, there are important time lags involved in production increases: vineyard maturity is typically reached after 5 years. This means that large productivity gains will be required particularly to achieve the short-term target. Given current production levels, the 2020 target set by the Government would require increasing production above current levels significantly. This incremental benefit (above BAU) would have an estimated value of £52 million and £108 million (at average and high value bottles prices respectively) over two years. If this target is met, the achievement of the 2030 and then 2040 targets is considered more feasible, requiring an annual (CAGR) 7% increase in bottle production.

The second goal of 20 million bottles would be 150,000 hectolitres. This would require productivity increases, but also more land dedicated to growing grapes. As noted by Nesbitt et al (2016), in Champagne yields can be more than 10,000 litres per hectare, thus there is the potential for considerable productivity improvements. Further, the Government has already identified 75,000 acres of land suitable for sparkling wine, some of which could be harvested in the next decade.

Assuming climate change leads to a 10% increase in production above the 2030 target (so additional 2 million bottles in 2030), this would have a retail value up to between £10.8 million and £50 million in that year alone (using average and high value bottles prices – current prices). A 25% increase above the target in 2030 would have a retail value between £26.95 million up to £100 million in that year. Similarly, a 10% increase above the 2040 target (equal to 4 million bottles in 2040) could translate to additional revenues to the sector worth between £21.6 million and £80 million in that year; a 25% increase, between £53.9million and £200 million; and a higher 50% increase, between £107.8 million and £400 million in 2040 (current retail prices). This productivity gains would occur gradually, with production increasing year by year until reaching the target or possibly going beyond it. Hence, annual incremental benefits (relative to production at 2017 levels) would occur.

Future benefits would arise from both productivity gains and from the increase in cultivated land (that becomes more suitable). For the former, the benefits are largely gained autonomously, as the improved climate increases production (notwithstanding the need to ensure management practice is able to capitalize on this theoretical improvement). For the latter, there are additional costs involved, because shifting areas to new production involves high investment capital by wine makers: £21,000 to £30,000/ha is typically required for vineyards (including planting materials and labour for establishment but not the land). The main benefit is therefore in an improved internal rate of return for these investments, i.e. climate change would improve the return on investment.

As noted above, the 2020 target looks like it will be difficult to achieve, and thus the 2030 target may also be difficult to achieve compared to a BAU scenario. In practice, therefore, it may be that climate change makes the 2030 target more likely to be achieved – rather than actually increasing productivity above the target. The economic values above can also be used as a proxy for this.

Potential impacts

However, there is also the potential for downside risks to increase. As set out above, increased climate variability can have negative impacts on wine production and quality, and could offset the benefits resulting from a warmer climate. There is insufficient information to estimate how important these changes might be, and the potential for benefits (reduced late spring frost) or impacts (more variability, leading to more extreme periodic frosts, or extreme heat). Nonetheless, a likely outcome is that English wine producers will face higher levels of climate variability. This could reduce the benefits from warmer temperatures outlined above.

There is also a further issue of how climate change might affect current wine growing areas, and thus affect their current comparative advantage, as shown in the earlier figures, these have not been quantified here. As highlighted earlier, climate change is projected to have major impacts in the geographic distribution of wine production, with some detrimental impacts on current areas.

Across these risks, there are some important thresholds. There are thresholds associated with the bioclimatic suitability for wine, and for different grapes (see earlier figure), which provide broad thresholds ranges. In most cases, these are not an immediate threat (to 2050) and England is actually like to move towards more optimal conditions. There is also a potential reduction in threshold levels for frost or extreme cold, though it is highlighted there is likely to be more variability which might counteract this. Autumn precipitation or summer deficits might be another threshold of concern, especially given the UKCP19 projections. Finally, there is the potential for extreme heat and thresholds: while heat extremes in the UK will increase, the levels are likely to be similar to current European wine producing areas, but they could be an issue for colder temperature grape varieties.

Finally, it is also highlighted that the expansion of cultivated area for wine involves long life-times and considerable lock-in, because it involves land-use change and high capital investment. The payback period on wine is longer than for many other agricultural crops, because of the time to mature. This means that early decisions on new expansion areas need to consider the future climate. These issues have been explored for other long-lived crops (e.g. for tea, see Watkiss, 2016).

It is stressed that there is a lack of information on these thresholds, and analysis of what climate change in England might mean for these. This warrants further assessment, and a priority is made for future studies to look at this, using the new UKCP18 projections.

Step 4. What are the potential additional adaptation options to address these impacts?

The case study has reviewed the existing activities for mainstreaming climate change in the sector. There is an active programme of support to help the wine industry develop opportunities, but this review has not found a strong climate component to this. This study has reviewed the available information on what Defra and the Great British Food Unit have delivered against the 2016 pledges with respect to providing new data and infrastructure network to the sector. It is not clear whether further work has been carried out on assessing the suitability of the 75,000 acres mentioned above, and if such analysis has taken future climate scenarios into account; nor if the private sector has already started investing in the land. The case study has therefore investigated further adaptation options that could be introduced to seize the opportunity presented by a warming climate, as well as to reduce the risks associated with climate variability. This has used the framework for early adaptation priorities shown below, which builds on the methods in use in CCRA2 (Warren et al, 2016) and CCRA3. This focuses on three types of adaptation that are considered together as a portfolio.

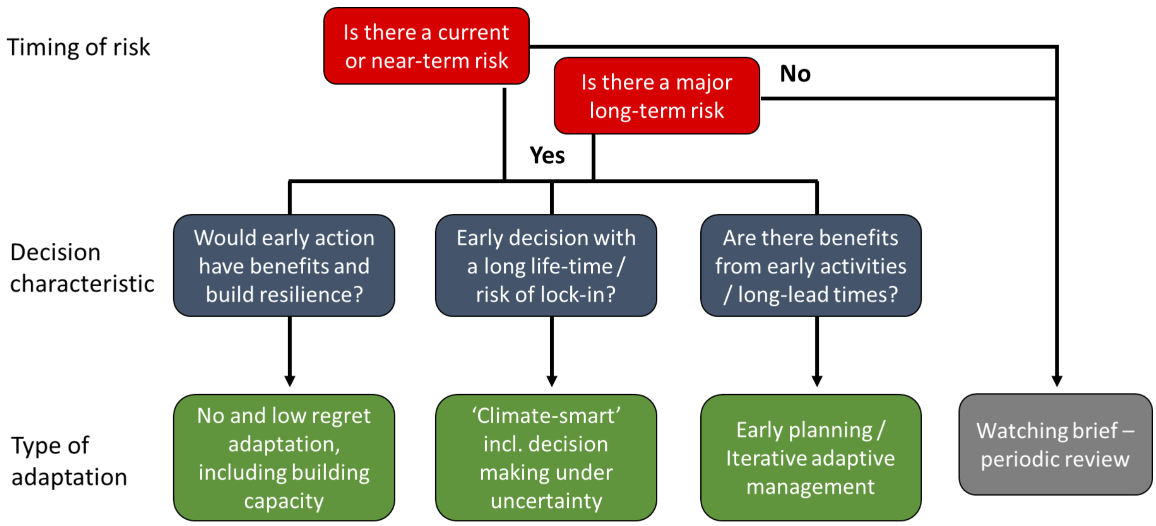

Figure 9 Early priorities for adaptation.

Source CCRA3 Method, based on CCRA2 (Warren et al, 2016: Fankhauser et al, Watkiss et al, Ranger et al.)

In terms of the opportunities of climate change, the main focus is for the Government to provide the enabling environment for the wine industry to take advantage of the positive changes in suitability and productivity. This could address the market failures that exist. Lack of information and uncertainty are two key failures in this case (Cimato and Watkiss, 2017). Defra has already pledged to gather and make available information on soil types, water resources, and infrastructure networks to identify the best areas of land for production. The objective is to help increase the area of planted vineyards from 2000 hectares to 3000 hectares by 2020, and potentially more by 2030. Also, using Defra's data, the Government has identified 75,000 acres across the country suitable for sparkling wine production. That is the equivalent of the champagne region, where production levels are currently around 10,000 bottles/ha.

Further work to expand this analysis to take into account climate change would be highly beneficial. This is particularly important given the lock-in involved with the expansion of wine production areas. Grapevines can live for 50 years or more, and climate suitability will change over time – and aligns to the second column in the figure above, i.e. climate smart decisions. As highlighted above, over the long-term, the south of England may become too wet or too warm for certain cool climate grape varieties, such as Pinot Noir. In the light of the lock-in risk, the information made available to the industry (soil, water, temperature) need to take into consideration future climate change, including potential changes in variability. This would prevent winegrowers from expanding and investing into areas that might become less suitable for certain grapes in 10-20 year time due to climate change.

In terms of the risks of climate change, it is highlighted that as climate variability already affects the English wine sector: enhanced adaptation to address to current climate variability would be a clear no- or low-regret response (column 1 of the figure above). Of course, winegrowers already have to address these risks, and adapting to variable conditions is a part of good viticulture practice, but the benefits of these actions and enhanced measures will be an important early option. There are also many lessons that can be drawn from other countries that already experience future changes (e.g. increased risks of heat extremes.) Neethling et al. (2014) conducted an empirical study in two areas in the Anjou-Saumur wine growing sub-region, France. Interviews with 30 winegrowers revealed that several adaptation responses to current climate variability are being adopted, with most adaptive responses occurring during harvest and winemaking (i.e., tactical and reactive). Winegrowers underlined that through various learning experiences, shared knowledge (i.e., practical and scientific) and changing viticulture practices, they enhance their adaptive responses (i.e., tactical or strategic) (Neethling et al. 2014).

Table 3 Types of adaptive responses used by winegrowers to manage diverse climate conditions (Neethling et al. 2014).

Adaptive responses	Climatic stimuli	Examples of viticultural practices
Tactical, reactive	Cool, wet	More severe leaf, shoot, crop thinning
	Warm, dry	Less severe leaf, shoot thinning
		Foliar nitrogen fertilization
	Wet ripening period	Several harvests via bunch selection
		Harvesting at night by machine
	Frost	Requesting crop insurance
		Turning on heaters/wind machines
Tactical, anticipatory	Cool, wet	Advancing canopy management practices
		Allowing natural vegetation to grow
		Higher number of fungicide treatments
	Warm, dry	Delaying canopy management practices
		Shallow soil tillage
	Frost	Delaying winter pruning
		Mowing cover crops
Strategic, reactive	Cool, wet	Longer cane pruning
	Warm, dry	Changing perennial cover crop species
		Increasing the trellis system height
Strategic, anticipatory	Cool, wet	Site selection
	Dry	Choice of rootstock variety
	Frost	Site selection, choice of grapevine variety

In terms of the risks from water variability, there is an important linkage to water demand and supply (see the case study on this), with the need for an integrated water management approach that considers climate change. The potential for English vineyards to take on board lessons from other countries (e.g. dry summer climate regimes) would be beneficial.

Neethling et al. (2014) report that, over the short term, winegrowers manage temporal variations in vine water supply through vine inter-row practices (i.e. tactical), in cases where anticipatory responses were considered to be essential. Contrary to reactive responses, anticipatory responses take action before critical thresholds are reached (e.g. severely restricted water supply), which can lead to irreversible impacts on grapevines. For vineyards with tilled or cultivated vine inter-rows, winegrowers allow weeds and natural grasses to grow during wet growing seasons. In addition to regulating vine vigour and improving vine earliness, weeds and natural grasses ensure good soil tractability for treatment, as wet conditions inevitably imply higher disease risks. Under normal and dry conditions, winegrowers will return to a clean cultivation or shallow soil tillage.

Over the long term, winegrowers manage vine water supply through the choice of annual and perennial cover crop species (i.e., strategic and reactive) or via site selection and choice of rootstock varieties before planting (i.e., strategic and anticipatory). In response to warm and dry trends over the last few decades, winegrowers from Coteaux du Layon have selected increasingly drought-resistant rootstock varieties. Improved cooling techniques such as water-efficient micromisters or strategic vine orientation/ trellising practices to control microclimates at the level of individual grape clusters can greatly reduce water use demands (Nicholas and Durham, 2012).

There is also a risk of changing pests and disease. An obvious adaptation action here would be to enhance monitoring and surveillance, making sure this is aligned to climate information. On managing fungal outbreaks, Neethling et al. (2014) report that winegrowers use physical, biological, or chemical adaptive responses to manage fungal pathogen risks or outbreaks (Nicholas and Durham 2012). Physical responses involve regulating vine growth directly or indirectly through canopy and vine inter-row management practices, respectively, where winegrowers defined a well-ventilated vine canopy to be less susceptible to disease.

With respect to managing late spring frosts, winegrowers' frost protection methods are reported to vary spatially and can be either passive or active. Passive protection includes indirect methods (e.g., site selection, pruning techniques) carried out in advance to reduce the vineyards' susceptibility to frost damage (Poling 2008). Active protection is the use of direct methods (e.g., wind machines, heaters, over-vine sprinklers), applied just before or during frost events. However, some active protection measures, such as installing heaters, and especially wind machines, have installation and operating costs and the investment is only justified for large vineyard surfaces. Generally speaking, Neethling et al. (2014) report that winegrowers avoid planting vineyards in frost-prone areas (e.g., low-lying) or select late-ripening varieties for those areas (e.g., Cabernet Sauvignon).

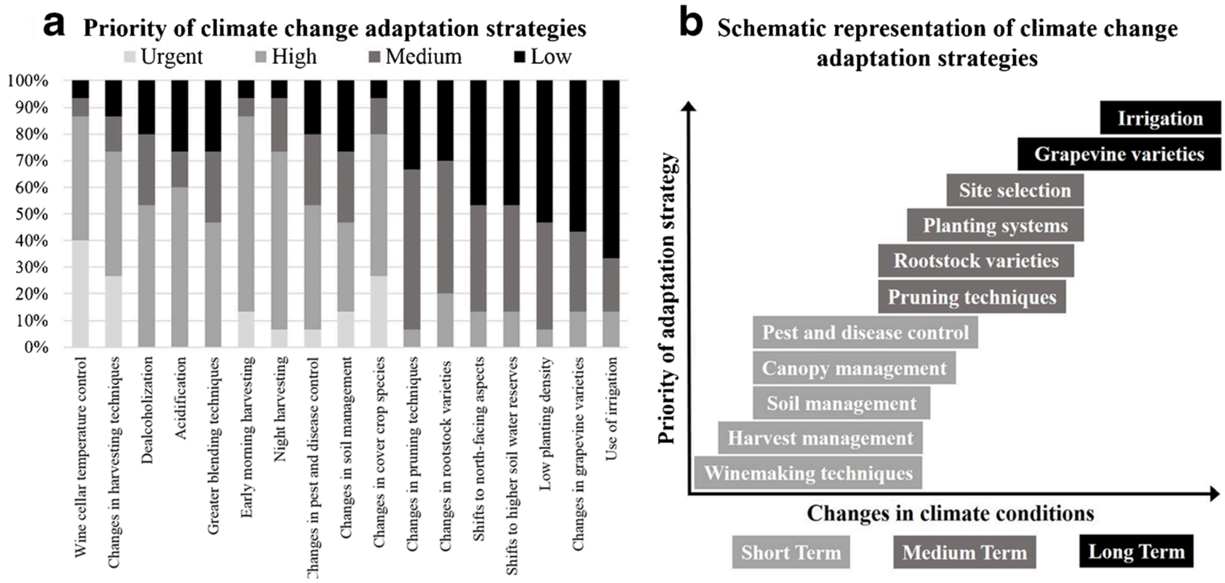

Figure 10 Based on the responses of winegrowers from Saumur Champigny, a) the priority of climate change adaptation strategies and b) its schematic representation in the short, medium, and long term over the twenty first century.

In general, Neethling et al. found that, faced with current climate variability and uncertainty of future climate change, winemakers place the highest priority on short-term adaptation strategies such as harvest management practices and winemaking techniques, while long-term adaptive responses (e.g. changing grapevine varieties and using irrigation for vine water supply) receive the lowest priority.

These studies do not provide information on the costs of these various techniques, as they generally fall into the ongoing /variable costs of managing a vineyard. Standard annual costs for wine production are just below £10,000/ha (see table below). These costs could be higher if climate variability increases requiring more frequent and costly interventions to reduce the potential losses resulting from climate variability. Either increasing costs or diminishing yields due to climate change would reduce margins to wine makers.

Table 4 Average costs to a commercial enterprise on a suitable site with a broad variety range

	Double Guyot	
	per ha	per acre
Number of Vines	3,000 - 5,000	(1,210 - 2,020)
	£ per ha	£ per acre
Establishment Costs:	over two years	
Materials	14,700	5,950
Labour	12,500	5,059
Total Establishment Costs	**27,200**	**11,009**
Subsequent Annual Costs:		
Materials	1,500	607
Labour (growing)	6,095	2,467
Harvesting*	1,600	648
Total Variable Costs	**9,195**	**3,721**

Source: John Nix farm management pocketbook (2015). Note h*arvesting costs are very yield dependent. Growers without wineries will also have transport costs.*

Adaptation strategies need to take into account the potential lock-in risk. In the case of this Outcome, such risk would arise from a poor understanding of future climate change on the sector productivity, the complex links with water availability projections, and the implications of a sector expansion on the ecosystems and the environment. For example, the establishment of a vineyard dependant on an irrigation system can hit a wall if the source of water is itself threatened by the change in climate (Viguie' et al. 2014).

In summary, the early adaptation options for this Outcome would include all three types of adaptation actions:

Type I) Low/No regret options. Low regrets measures would include those actions aimed at managing current climate variability. For example, preserving the soil and increasing its level of organic matter are likely to have quite rapid beneficial effects on the vine, while limiting the effects of more sporadic rainfall. Wine-making techniques aimed at reducing the alcohol content could also be considered as low-regret, since an increase in the percentage of alcohol is already penalised in many markets, and being able to reduce alcohol content can increase the saleability of wines in these markets as well as anticipate a trend that will continue (Viguie' et al., 2014). Further, adopting water-efficient measures would have several co-benefits and be beneficial today as well as in case of future water scarcity. Given the current exposure to late spring frosts, passive (e.g. low-cost) protection measures could be adopted. Similarly, adopting canopy management strategies could help manage heat-related stresses.

Type ii) Early decisions with a long life-time. In the case of this Outcome, the objective of increasing the production area by 1000 hectares by 2020, and harvesting additional hectares (of the 75,000 acres - equal to 30,351 hectares – identified by the Government) for sparkling wine production, carries a potentially high lock-in risk. With proper care, grapevines can live for 50 years or more, and if the complex land-water-ecosystem nexus under future climate change is ignored, then mal-adaptation might occur resulting in high costs for the industry as well as for the environment. An enabling environment should be promoted to support adaptation measures that are not only effective for moderate warming but will not constrain future action or have negative consequences in the long-term, when warming will be greater. It is crucial that those areas identified as suitable for wine-growing today will remain suitable under future climate warming; and that ecosystem services will not be damaged by an expansion of wine-growing areas. Climate risk screening, land-use plans, and research would therefore be key to creating an enabling environment to help winegrower adapt and the sector to grow.

Type iii) Early actions to address long-term risks. Early research and monitoring programmes could be promoted to support the industry seize the opportunities and manage the long-term challenges posed by climate change. This could include enhanced climate information and analysis, as well as enhanced monitoring and surveillance of pests and disease.

As above, it is stressed that there is a lack of information on extreme thresholds, and analysis of what climate change in England might mean for the exceedance of these. This warrants further assessment, and a priority is made for future studies to look at this, using the new UKCP18 projections.

A key message is that in order to take advantage of opportunities, the wine sector also needs to address potential risks of variability, i.e. there is a need for both to fully realise benefits.

Step 5. What are the benefits and costs of adaptation, including trade-offs?

A high-level (indicative) economic assessment of the potential costs and benefits of adaptation has been conducted. First, the benefits of achieving the current objective (without climate change) of 10 million bottles in 2020 was estimated, which assumes production remains constant on average at the 2017 level (3.86 million bottles). The benefits of the additional bottles produced were then estimated at the average retail price of £5.39 (constant price, no inflation). Benefits for future scenarios were then estimated against the costs of investing in a growing wine industry, with and without adaptation. Three scenarios were modelled: 1) The current outcome scenario 2) the Adaptation scenario under 2^{o}C degree and 3) Adaptation scenario under 4^{o}C degree. It should be emphasised that all scenarios exclude costs to Government of new information, and the costs of purchasing land to wine growers. The former are likely to be low. The latter are likely to be high.

1) Baseline outcome scenario. Even before considering climate change, achieving the Government objective would have costs, including:
- The Government costs of producing soil types, water resources, and infrastructure network information; and making it available to winegrowers to help them improve productivity, and plan for investment. These costs could not be estimated, although they are unlikely to be especially large.
- The costs of establishing new vineyards for 1000 hectares by 2020. This is estimated roughly at £27.2 million (establishment costs), plus ongoing costs of £9.15 million per year until 2040.
- The costs of growing sparkling wine in additional acres (identified by the Government as suitable) by 2040. The total area identified as being suitable is 75,000 acres or approximately 30,000 hectares of land. Assuming (conservatively) that 3,000 of this area is gradually cultivated by 2040, this would bring the total wine cultivated area in the UK to 6,000 hectares (hence double relative to the 2020 objective) in 2040. The price has been conservatively assumed at the average price (£5.39) also for sparkling wine.

Based on these assumptions, the 'baseline scenario' generates a NPV that at 10% discount rate (reflecting the private nature of investment, not Government social discount rate) is positive at £378 million. Failing to achieve the objectives completely would therefore cost £378 million to the economy, or £42.5 million per annum worth of benefits (annualised net benefits). Productivity under these assumptions would need to be on average (over the period 2020-2040) 3554 litres/ha.

2) Adaptation scenario under 2^{o}C. By adding climate change adaptation, the model assumes a scenario where:

- Wine growing areas are expanded further, with an additional 3,000 hectares cultivated by 2040 (compared to the 'Baseline outcome scenario'), bringing the total cultivated area to 9,000 hectares in that year. Given the potential areas identified by Defra, this is a conservative assumption;
- Production increases by 40% compared to the 'baseline outcome scenario' described above. This is assumed as resulting from both an increase in cultivated land and productivity gains;
- To achieve such gains, wine growers improve land management and strengthen monitoring to manage increasing climate variability, something which is assumed to increase operation and maintenance costs by 10% relative to the baseline outcome scenario.

Under these assumptions, the NPV in this scenario is higher than in the Baseline scenario, reaching £628 million, or generating £70.7 million worth of net benefits per annum. Productivity would be higher, or on average 3725 litres/ha.

3) Adaptation scenario under 4°C degree. In this scenario, it is assumed that annual production could increase even further, but so would the costs to manage increasing climate variability.

- Wine growing areas are expanded, with additional 5,000 hectares cultivated by 2040, bringing the total cultivated area to 11,000 hectares in that year.
- Production increases by 60% compared to the 'baseline scenario' described above. This is assumed as resulting from both an increase in cultivated land and productivity gains;
- To achieve such gains, wine growers improve land management and strengthen monitoring to manage increasing climate variability, something which is assumed to increase operation and maintenance costs by 20% compared to the baseline outcome scenario.

Under these assumptions, the NPV in this scenario is higher than in both the Baseline scenario and the Adaptation 2°C degree scenario – NPV would be £640 million, with annualised benefits worth £72 million.

The results indicate that under a scenario where wine growers were able to realise the benefits of climate change due to better information (and appropriate response), and at the same time introduce adaptation measures to address potential variability risks, there would be very large economic benefits (£0.6 billion present value by 2040, around $70mpv/year), and a high benefit to cost ratio.

These findings are only indicative and based on a number of assumptions which have not been discussed with professional winegrowers (e.g. the relationship between productivity gains and cultivated land). Productivity gains due to climate change also are highly uncertain, hence are arbitrarily assumed. So are the O&M cost increases due to climate variability.

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