LIFE-ADVICLIM PROJECT: PLUMPTON PILOT SITE

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FOREWORD

There is growing evidence that climate change is taking place throughout the world. Observed regional changes include rising temperatures, shifts in rainfall patterns and extreme weather events. Climate change is expected to continue in the near future, and have important consequences on viticulture. These vary from short-term impacts on wine quality and style, to long-term issues, such as varietal suitability and the economic sustainability of traditional wine producing areas. As a result, the wine industry is facing many challenges, which include adapting to these potential impacts, as well as reducing greenhouse gas emissions related to their activities.

In response to these challenges, the LIFE-ADVICLIM project aims to evaluate and develop local climate change adaptation and mitigation strategies. This project's measurement network and web platform aims to inform vinegrowers on climate change impacts, rational adaptation scenarios and greenhouse gas emissions related to their practices at the vineyard scale. These technologies are evaluated in several European wine growing regions (Figure 1), namely Bordeaux and Loire Valley (France), Sussex (England), Rheingau (Germany) and Cotnari (Romania). The region of Navarra (Ausejo and Carbonera vineyards) in Spain is an associate study area. These six regions represent the climatic diversity of European wine producing areas, ranging from the Mediterranean to oceanic and continental climates.

For more information on this project, visit https://www.adviclim.eu/

Figure 1: Position of the six European wine growing regions studied in the LIFE-ADVICLIM project.

INTRODUCTION

Climate is changing across the word, especially through an increase in temperatures and the modification of rainfall. Vine development and grape composition are strongly related to climate, so climate modification is a major challenge for wine production. The aim of the Life-ADVICLIM project is to evaluate and develop local climate change adaptation and mitigation strategies.

This report presents the main results obtained in the Rock Lodge pilot site (managed by Plumpton College) for the B3 action, which aims to synthesize all the Life-ADVICLIM results.

General presentation of the Rock Lodge (Plumpton College) pilot site

Global warming has enabled the English wine industry's very rapid expansion and rising reputation within the UK wine market; the ability of grapevines to ripen grapes successfully in the English climate is very strongly linked to temperature. However, regional climate measurement is not precise enough to provide useful information on a vineyard scale, as the weather within a vineyard plot is very strongly influenced by physical factors and surrounding features.

Rock Lodge Vineyard was established over 50 years ago, and is located in the Southeast of England in the county of Sussex, near the town of Haywards Heath (50°59'19''N, 0°02'26''W). The south of this county is bounded by the English Channel and the chalky South Downs, but most of the area consists of low-lying clay soils (the Weald), crossed by sandstone ridges. This region is one of the most forested regions in the UK, but highly populated, due to its proximity to London. Rock Lodge is located in the Weald on a sandstone ridge, also consisting of siltstone, mudstones, limestone and clay ironstone (Rawson, 1992; British Geological Survey, 2017). The site's soil, a slightly acidic clay loam with a sandstone subsoil, is well adapted to viticulture and is shared by many successful English vineyards. The surrounding area is wooded, with some mixed agriculture. Rock Lodge vineyard has a total area of 7.3 ha, and consists of two parcels: Pond Field, to the west (2.3 ha), and Deer Field (5.0 ha).

The vine rows are planted in a north-south orientation on a south-facing (6.9% average) slope with its highest point at 70 metres and lowest at 30 metres above sea level. All vines are trained in a vertical shoot positioned (VSP) trellis and pruned to single or double Guyot, according to vigour. Standard vine spacing is 1.2m and row width is 2.2m. The site was cultivated prior to planting, but, once established, the vineyard floor is managed by mowing rough pasture (native species) in the alleys, with the under-row area kept weed-free with herbicides and cultivation. The vineyard is managed in a conventional fashion, though there are many areas where trials have been established for research purposes. For the duration of the study, all of the vines were subject to the same viticultural practices in terms of spray programme, pruning, leaf stripping, fertilisation, and vine trimming.

The most popular grape varieties in England are Pinot noir, Chardonnay, Pinot Meunier, and Bacchus. As the vineyard has primarily an educational and research function, many grapes varieties are cultivated in this vineyard, including the major Champagne varieties: Chardonnay, Pinot noir & Pinot Meunier. Other varieties include Dornfelder, Rondo & Acolon (black varieties) and Bacchus, Riesling, Regner, Pinot Banc, Seyval and Ortega (white varieties).

Pinot noir is an early-ripening black variety, which is extremely sensitive to climatic influences. It grows well in England and is the most cultivated variety, occupying 31.5% of the English vineyard surface. The cool English autumn allows Pinot noir to ripen under just the right conditions for the distinctive flavour compounds required for quality sparkling wine (H. Johnson & J. Robinson, 2019).

Chardonnay is a white grape variety originating from Burgundy. It is one of the principal grape varieties used in the production of Champagne and English sparkling wine, representing 30.2% of the grape varieties cultivated in the UK (H. Johnson & J. Robinson, 2019).

Pinot Meunier is a black variety, essential to the production of both Champagne and English sparkling wine, representing 9.5% of the English vineyard area. It tends to be planted in the cooler parts of the vineyard, as its budburst is later (so there is a reduced risk of spring frost damage) and it requires less total annual heat summation to ripen its grapes than Pinot noir. (H. Johnson & J. Robinson, 2019).

Bacchus is a white German variety that grows very well in cool viticultural climates, producing fresh, aromatic still wines in the UK. It covers 5.6% of the UK vineyard surface area (H. Johnson & J. Robinson, 2019).

Objective of the LIFE-ADVICLIM Action B3 (Figure 2)

In order to measure temperature variability over this pilot site, and its link with grapevine development and berry composition, a network of 19 temperature sensors and phenological observation plots were set up. Temperature maps at the field scale were produced, and the spatial distribution of temperatures throughout the site was analysed. The grapevine response to temperature variability was studied, as well as the relationship between temperature and grape composition.

The climate and phenological models developed in this first step were then coupled with regional climate change models based on RCP (Representative Concentration Pathways, see van Vurren et al (2011)) scenarios 4.5 and 8.5, and the effect on vine development assessed. The current cultural practices performed in the plot were then identified, and their evolution modelled according to different climate change scenarios. These results were used to identify adaptation strategies at the vineyard scale, in order to support vinegrowers in their efforts to cope with climate change. The sustainability of viticultural practices, now and in the future, was evaluated in terms of the production of greenhouse gas (GHG) emissions, environmental impacts and socio-economic impact.

All these results provide key climate change adaptation and mitigation information for local vinegrowers.

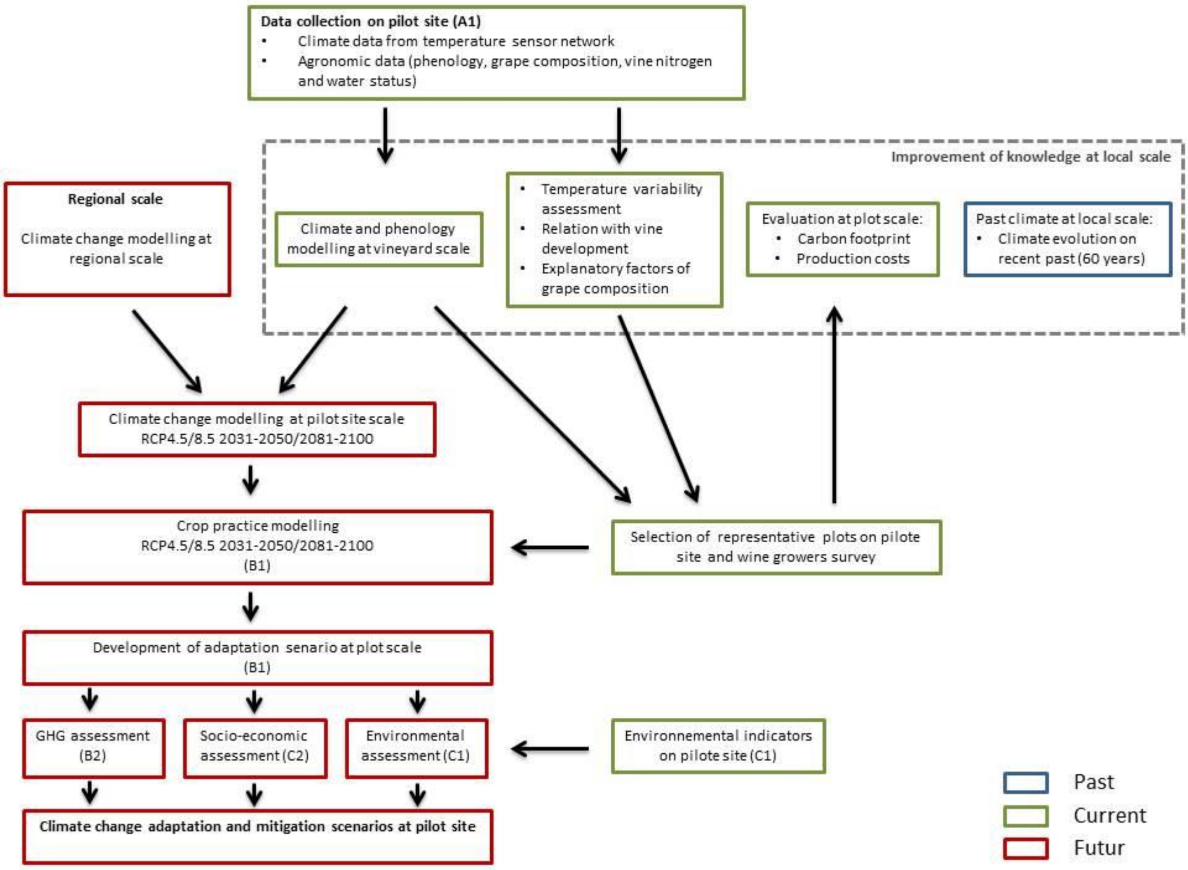
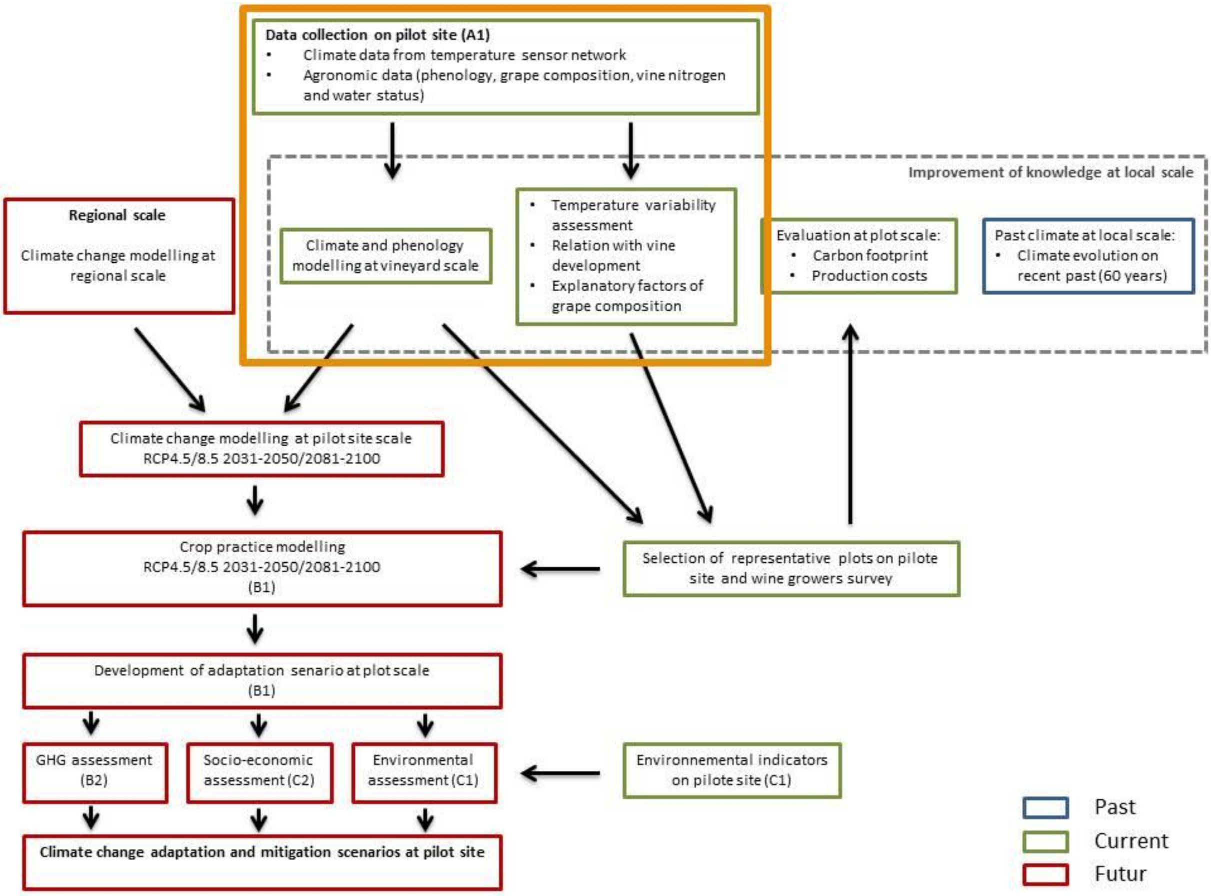


Figure 2: B3 action objectives

PART 1: FROM OBSERVATION TO MODELISATION AT THE VINEYARD SCALE



In this project action, climate and agronomic observations were carried out at the vineyard level using a network of temperature data loggers on the Rock Lodge site. These field observations were combined with local environmental features, then integrated into a spatial analysis model.

1.1 Agro-climatic measurements implemented at the vineyard scale

15 temperature sensors (Tinytag Talk 2 TK-4023), held within RS3 thermal radiation protection screens and positioned within the vine canopies at a height of 1.5 m, were installed in 2015, plus a further 4 sensors in 2016. Each sensor was set to measure hourly maximum and minimum temperatures. These sensors are capable of reading temperatures between -40 to 125°C with a precision of ±0.4°C and a resolution of ±0.05°C.

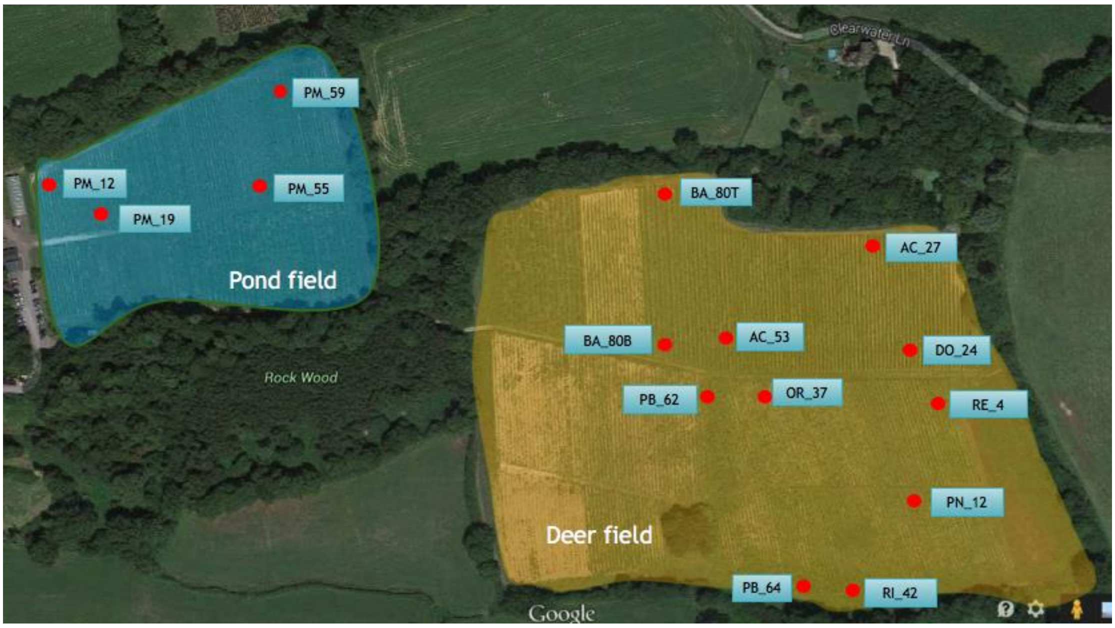


Figure 3. Positioning of temperature sensors in the field at Rock Lodge vineyard

Figure 3 shows the position of these sensors within the vineyard fields at Rock Lodge and table 1 gives the position of each sensor, as mapped on the UK National Grid using a Satmap Active 122 Solo geographical positioning system. Data, from the Defra Data Services Platform, with a resolution of two metres was used to obtain the topographical features.

Table 1. Physical properties of the temperature sensor positions at Rock Lodge vineyard

Variety	Sensor	Alt (m)	Slope (°)	Orientation
Pinot Meunier	PM_12	58	5.4	South
Pinot Meunier	PM_19	55	6	South
Pinot Meunier	PM_55	56	3	South-east
Pinot Meunier	PM_59	60	4	South
Acolon	AC_27	44	4.4	South-east
Acolon	AC_53	44	1.9	South
Bacchus	BA_80T	49	3.7	South
Bacchus	BA_80B	44	1.8	South
Dornfelder	DO_24	42	4.2	North-east
Ortega	OR_37	44	1.8	South
Pinot Blanc	PB_62	44	1.8	South
Pinot Blanc	PB_64	36	5.5	South
Pinot Noir	PN_12	42	2.2	South
Regner	RE_4	42	4.4	North-east
Riesling	RI_42	33	4.8	South

Over the three years of this study, data was gathered and analysed relating to the site's topography and temperature variation (including a range of bioclimatic indices) and grapevine phenological observations. Unfortunately, the vineyard suffered a catastrophic frost event on the night of the 27th April 2017; most of the data for the 2017 growing season was untypical, so could not be used.

The map on figure 4 shows the altitude variation within the site, whereas figures 5 and 6 display the variation in aspect and slope.

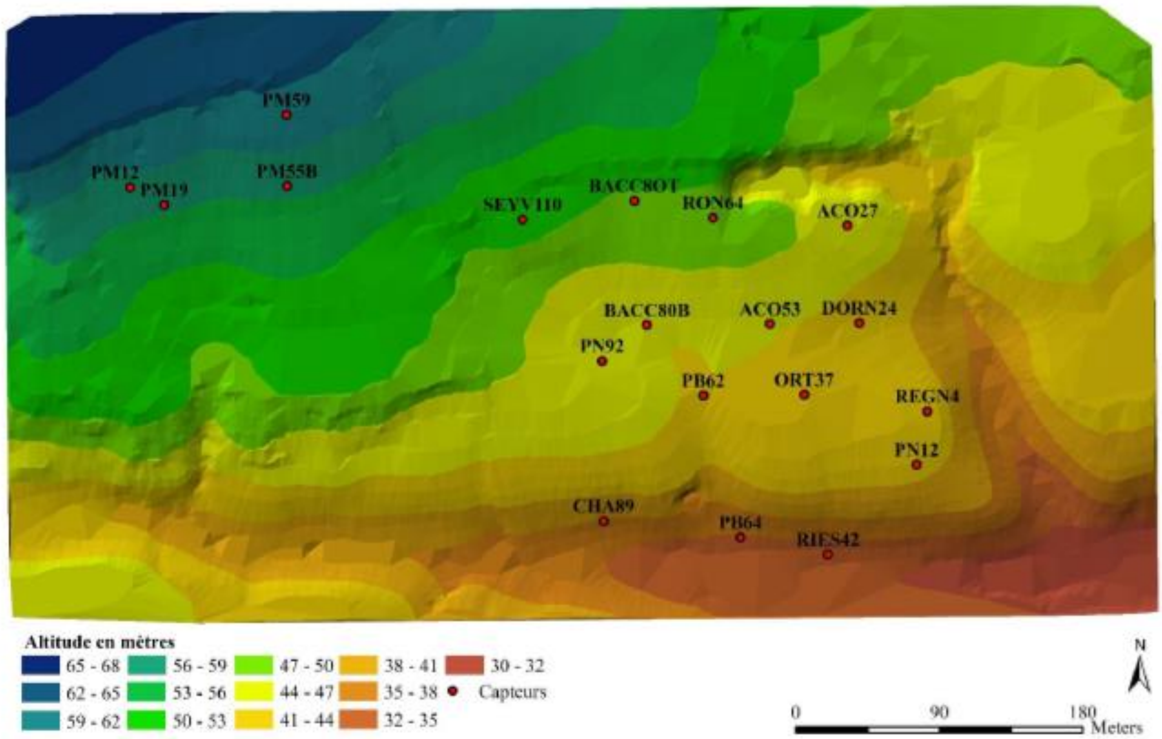


Figure 4: topographical map of Rock Lodge Vineyard, displaying altitude and positioning of ADVICLIM project temperature sensors.

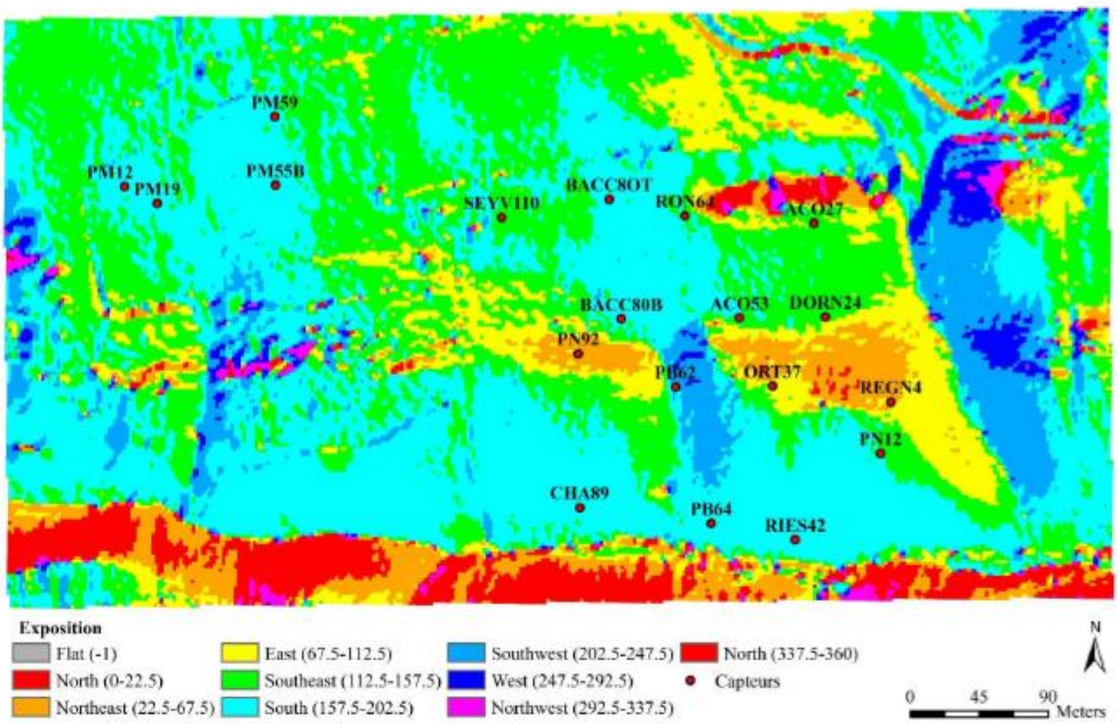


Figure 5: topographical map of Rock Lodge Vineyard, displaying orientation and positioning of ADVICLIM project temperature sensors.

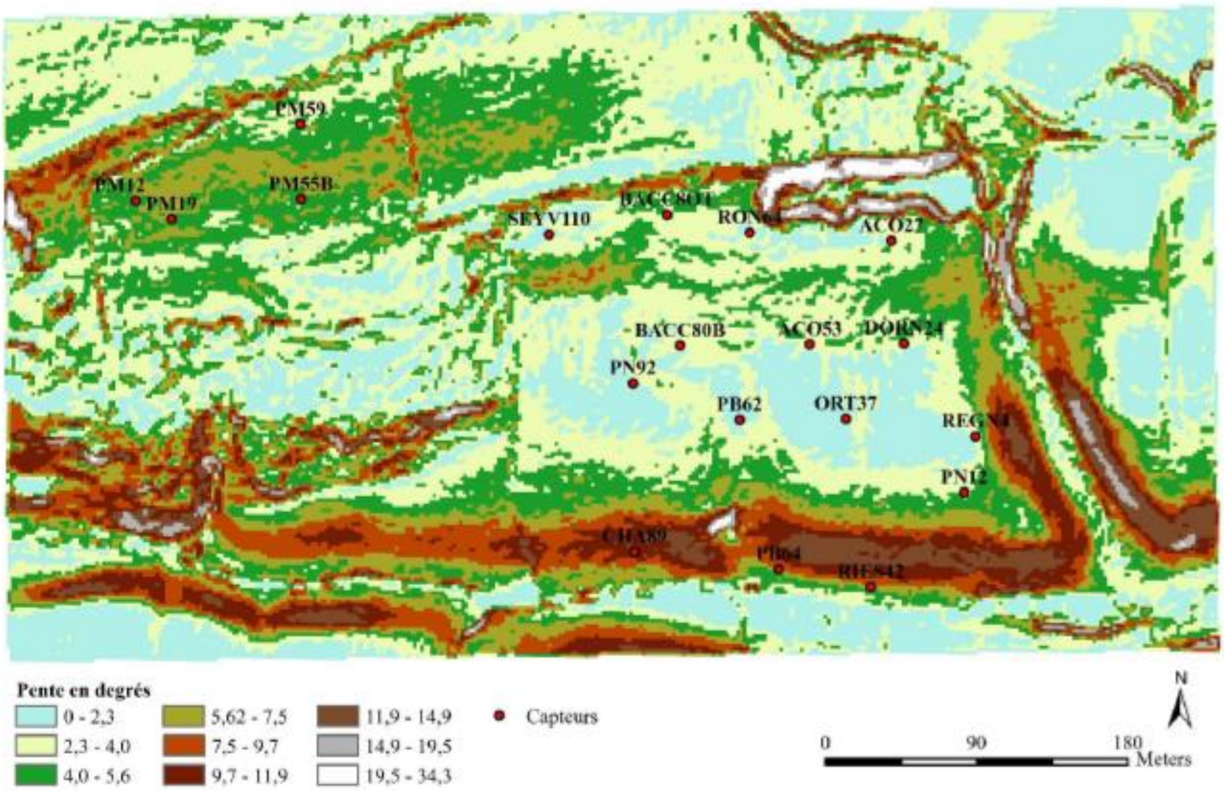


Figure 6: topographical map of Rock Lodge Vineyard, displaying slope and positioning of ADVICLIM project temperature sensors.

The data recorded by the sensors was downloaded using Tinytag explorer software (Gemini Data Loggers Ltd) and analysed using an Excel spreadsheet to generate daily maximum (Tmax), minimum (Tmin) and mean (Tmean) temperatures for two consecutive vegetative seasons (2015 and 2016). From these daily dataset, the following bioclimatic indices (BCIs) were calculated for each sensor: Winkler Index (WI), Growing Season Temperature (GST), Cool Night Index (CNI) and Latitude-Temperature Index (LTI). Statistical analyses were performed in order to identify the intra-site spatial differences.

Ecophysiological measurements were carried out, to monitor grapevine development and berry composition, on the 20 vines located nearest each temperature sensor. These vines were monitored for phenological stages (budbreak, flowering and veraison) with the specific day when 50 per cent of vine organs reach stage "C" for budbreak, stage "I" for flowering and stage "M" for veraison recorded (Baggiolini, 1952).

A maturity control on 60-berry samples was carried out for all the blocks at the same date, each year. The mean berry weight, total reducing sugars, total acidity (TA), and pH levels were determined.

1.2 Temperature analysis at the local scale

Climate evolution in the recent past

According to the IPCC (2013), the average global air temperature increased during the 20th century by 0.85 °C. This growth has altered the base climate of the wine regions on globe and the thermal intervals to which wine grape varieties specific to these regions are adapted (Jones et al., 2005). Starting from this general finding, the ADVICLIM project studied the structural and spatial shifts that occurred between 1951-2010 in climate suitability for viticulture of all wine growing regions represented in the ADVICLIM project. Climate suitability was assessed based on the changes in multiannual averages and spatial distribution between 1951-2010 of the Huglin Index (HI; Huglin, 1978), Oenoclimate Aptitude Index (IAOe; Teodorescu et al., 1987), Average Growing Season Temperature (AvGST; Jones, 2006), annual average temperature (AAT, °C), sunshine duration for the growing season (ASD, hours) and precipitation during the growing season (PP, mm).

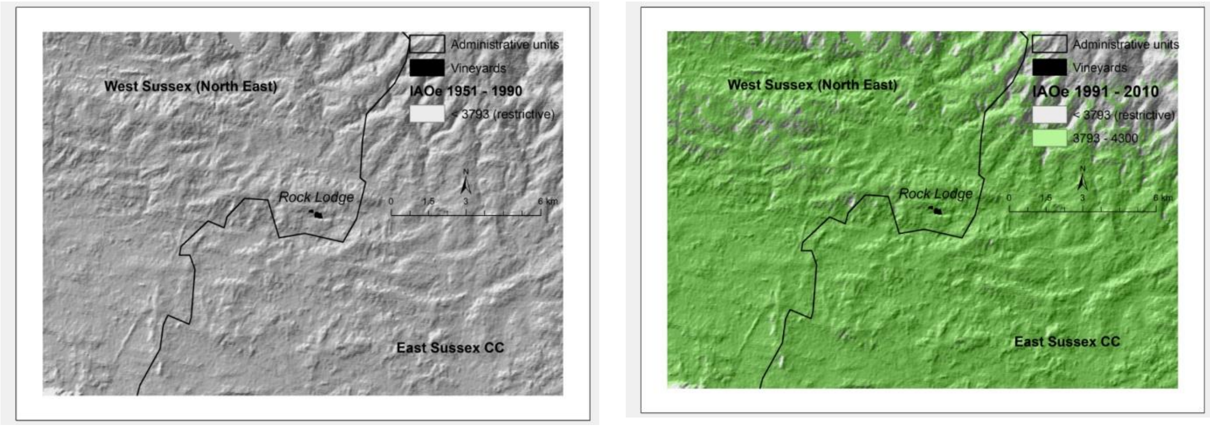
For the Rock Lodge pilot site (Sussex), our research revealed an increase of about 0.8°C in the average annual temperature (AAT) for the 1951-2010 time period, from 10.5°C in the recent past 1951-1990 time period to 11.3°C between 1991-2010. During the 1951 and 2010 the precipitation in the growing season (PP) maintained quite stable, with an insignificant increase of 3.4 mm from one time period to another. These developments of the AAT and PP shifted the multiannual averages of bioclimatic indices and implicitly the suitability of local climate for the wine production (Table 2).

Table 2. Statistics for the evolution of some climate parameters and bioclimatic indices for the Rock Lodge pilot site, for the 1951-1990 and the 1991-2010 time periods (ADVICLIM Project)

Climate parameters	Min	Max	Range	Mean	STD
Sunshine duration (hours)	1171.2	1280.4	109.1	1236.8	26.76
Huglin index (units), 1951 – 1990	1075.2	1083.3	8.0	1078.5	2.16
Huglin index (units), 1991 – 2010	1249.8	1257.9	8.0	1253.1	2.16
IAOe (units), 1951 – 1990	3629.9	3745.7	115.7	3696.8	28.67
IAOe (units), 1991 – 2010	3772.9	3888.7	115.7	3839.8	28.67
Precipitation (mm), 1951 – 1990	326.2	331.5	5.2	328.3	1.41
Precipitation (mm), 1991 – 2010	329.6	334.9	5.2	331.7	1.41
Average annual temp. (°C), 1951 – 1990	10.4	10.5	0.1	10.50	0.03
Average annual temp. (°C), 1991 – 2010	11.2	11.3	0.1	11.30	0.03
AVGst (°C), 1951 - 1990	13.8	13.9	0.09	13.87	0.0
AVGst (°C), 1991 - 2010	14.6	14.7	0.09	14.67	0.024

The multiannual average of the Huglin index (HI) increased by 174.6 units, from 1078.5 units during the 1951-1990 period to 1252.10 during the 1991 to 2010 period. The HI average still maintains in the *very cool climate class* HI-3 (< 1500 units), characterised as unsuitable for grapevine growing, but its increase reveals a definite improvement of local climate suitability for wine production. This ascertainment is also sustained by the AvGST evolution (Table 2): it maintains in the cool climate class (13-15°C) but with a higher value of 14.67°C, closer to the upper limit that make transition to intermediate class (15-17°C) suitable for Sauvignon, Chardonnay, Cabernet Franc, Pinot noir varieties (Jones, 2006).

The Oenoclimate Aptitude Index (IAOe) reveal a clear shift from the unsuitable climate for grapevine growing between the 1951-1990 time-period to the suitability for white wine production today (Figure 7). 87.06% of the studied area is suitable today for the white wine production, as compared with 0% during the 1951-1990 time-period (Figure 7 and Table 3).



a. b.

Fig. 7. Maps of the Oenoclimate Aptitude Index (IAOe) for the Rock Lodge pilot site for the 1951-1990 (a) and 1991-2010 (b) time periods.

Climate suitability for the wine production is differentiated in the Rock Lodge area on altitude (Table 2): the suitable area is located between 4 and 173 m ASL, with an average altitude of about 48.16 m ASL, while over 173 m ASL the local climate is not suitable for the wine production (Table 3).

Table 3. Statistics for the spatial distribution of the IAOe index in the Rock Lodge area, during the 1951-1990 and 1991-2010 (according to ADVICLIM project)

Classes of the IAOe	**Area** (km^2)	**Elevation (m, ASL)** Min	Max	Range	Mean	STD	**Structure of climate suitability** (%, area)
				1991-2010			
0 points	39.62	9.00	197.00	188.00	**105.5**	38.70	12.93
5 points	266.74	4.00	173.00	169.00	**48.16**	23.38	87.07
Total	**306.36**	-	-	-	-	-	**100.00**

Temperature variability of the vegetative season

The daily mean, minimum and maximum temperatures were analysed during the growing season (from April 1st to September 30th) for four consecutive years (2015-2018) (Figure 8).

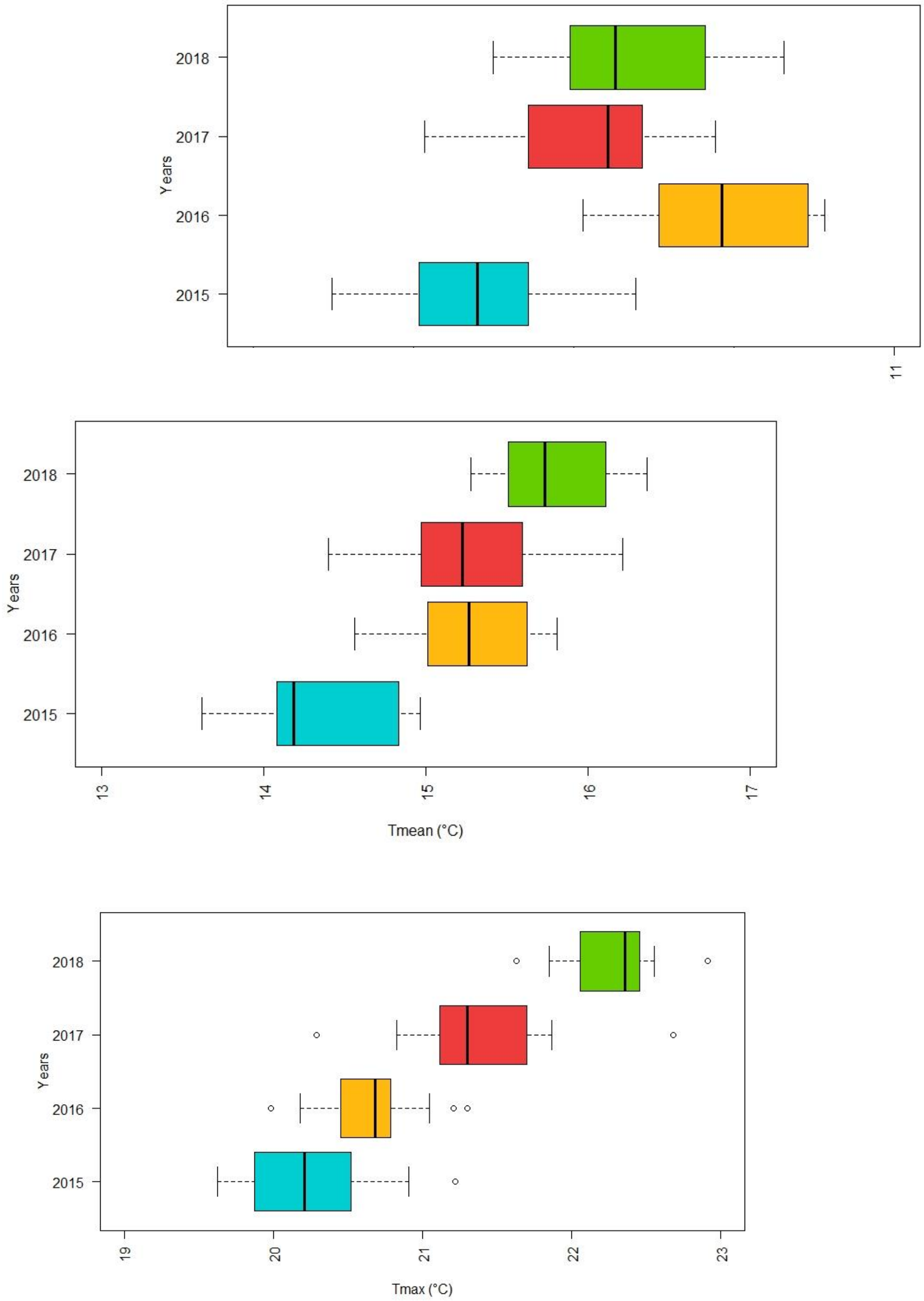


Figure 8: Boxplots of mean, minimum and maximum average daily temperatures over the growing season (from April 1st to September 30th) from 2015 to 2018

These boxplots indicate that, according to mean temperatures, 2015 is the coolest year, then 2017 and 2016, with 2018 being the warmest year. 2015 was also the coolest from the point of view of minimum and maximum temperatures. 2018 was also warm, from both the point of view of minimum and maximum temperatures, and 2017 consistently positioned between 2015 and 2018. In fact, 2018 was the warmest year in the UK since records began, and the joint hottest summer on record (with 1976, 2003 & 2006). The surprising result was 2016, for which unusually high minimum temperatures were recorded. In fact, the winter of 2015-16 was the UK's warmest, and second wettest, since records began (1659). The summer of 2016 was significantly cooler than 2017, but the high winter temperatures were sufficient to enable the mean temperature to be greater. The boxplots display a greater difference in within-year amplitude in the minimum temperatures, as opposed to maximum temperatures. This may be linked to the sloped topography of the site, which encourages cold air to drain to the lower regions.

These boxplots do not show the disastrous advection frost that affected the South East of England on the night of the 26-27th April 2017, which destroyed all the green shoots in the vineyard, generating an atypical year with very low yields of poorly ripened grapes, harvested late in the season.

Bioclimatic Indices: Huglin Index

The Huglin degree-days summation, which is well adapted to study the influence of temperature on vine development, is used in order to improve the characterisation of climate variability. This index is based on the sum of temperatures above 10°C, from April 1st to October 31st (in the northern hemisphere), modified for latitude, thus taking into account increased day length for northern latitudes. When these temperatures are measured inside the canopy, this index is referred to as the Canopy Huglin Index.

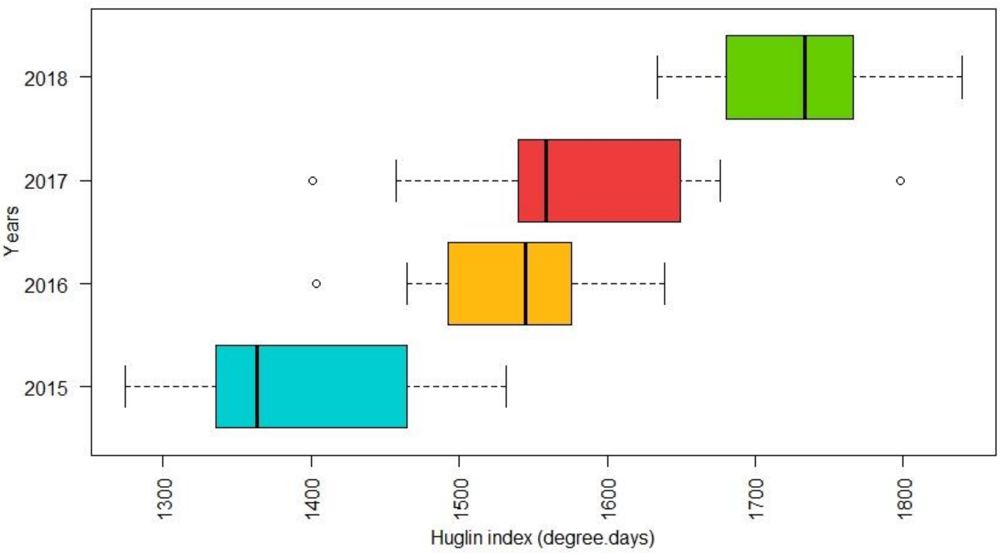


Figure 9: Boxplots of Canopy Huglin Index from 2015 to 2018

Figure 9 displays an average intra-annual range (Average difference between your coldest sensor and your hottest sensor) from 2015 to 2018 of 274 degree days, which is surprisingly high for a single field. This figure would be expected as a difference between different areas within a large region, such as the South East of England. 2016, the year with the warmest winter, has the narrowest range of degree days, confirming that minimum temperatures have a strong effect on the amplitude of temperature readings.

Climate modelling adapted to the vineyard scale

The non-linear regression model (SVR) presented in action A1 (Le Roux et al., 2017) was used to map temperatures at the Rock Lodge pilot site.

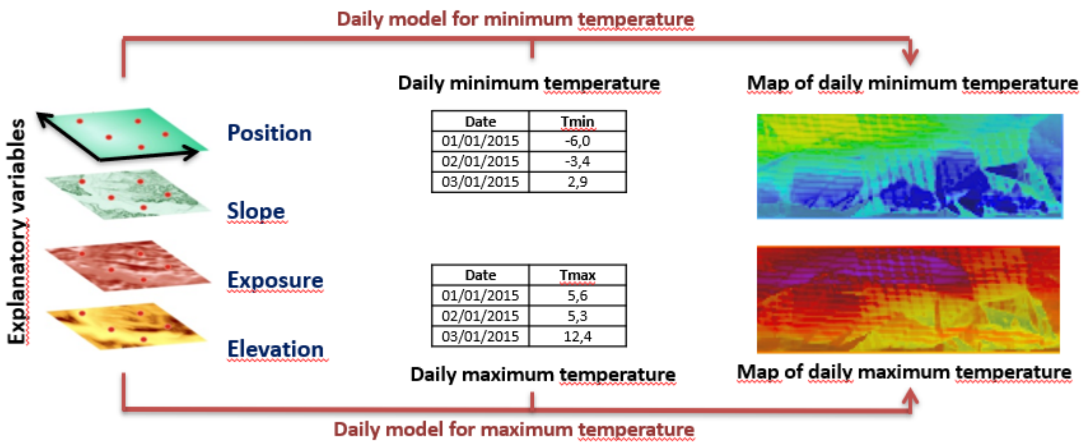


Figure 10: Schematic representation of the production of daily temperature maps

Using the data extracted from the data loggers, the model allows the mapping of the daily maximum and minimum temperatures over the studied years (2015-2016) (Figure 11) and the spatialisation of the relationships between the temperature distribution and the local environment. Based on these daily maps, the average minimal and maximal temperatures and the bioclimatic indices mentioned above were mapped in order to visualise their spatial variability. The models (Tmin, Tmax, WI, and HI) show a recurring spatial structure as well as a vintage effect. It was therefore decided to average all the temperature maps in order to be able to quantify the temperature distribution and produce a temperature zoning.

The analysis of the average minimum (Tmin) and maximum (Tmax) temperature maps over the studied years revealed a very high spatial variability. For Tmin, the sector with the highest altitude (the top of the slope), and those on southerly-exposed part of the slope, correspond to the areas with the highest minimum temperatures. Conversely, the lowest sectors (valley bottom) are associated with the lowest temperatures, which may be due to the effect of thermal inversion situations and topography (Beltrando and Chémery, 1995).

For the spatial distribution of maximum temperatures (Figure 11), a similar spatial pattern is observed: the warmest temperatures are recorded at the top of the slope and the cooler temperatures lower down. The spatial amplitude of the mean maximum temperatures is smaller compared to the minimum temperatures.

Finally, the areas with the greatest amplitude between minimum and maximum temperatures are located at the bottom of the hills, while the parcels located in the highest positions show less variability.

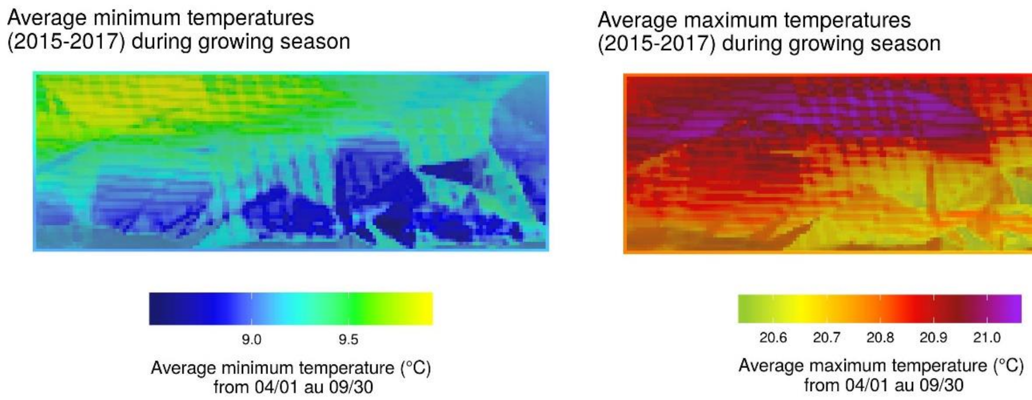


Figure 11: Spatial distribution of average minimum and maximum temperatures during the growing season (2012-2017)

Canopy Huglin Index

The Huglin index, because of the way it is calculated, gives a greater significance to maximum temperatures. The highest points on the south-facing slope are those with the highest index values on the Rock Lodge site. The low-lying parts of the study site are the areas with the lowest index values (figure 12). It is interesting to note that there is an amplitude of over 50 degree days within such a small area.

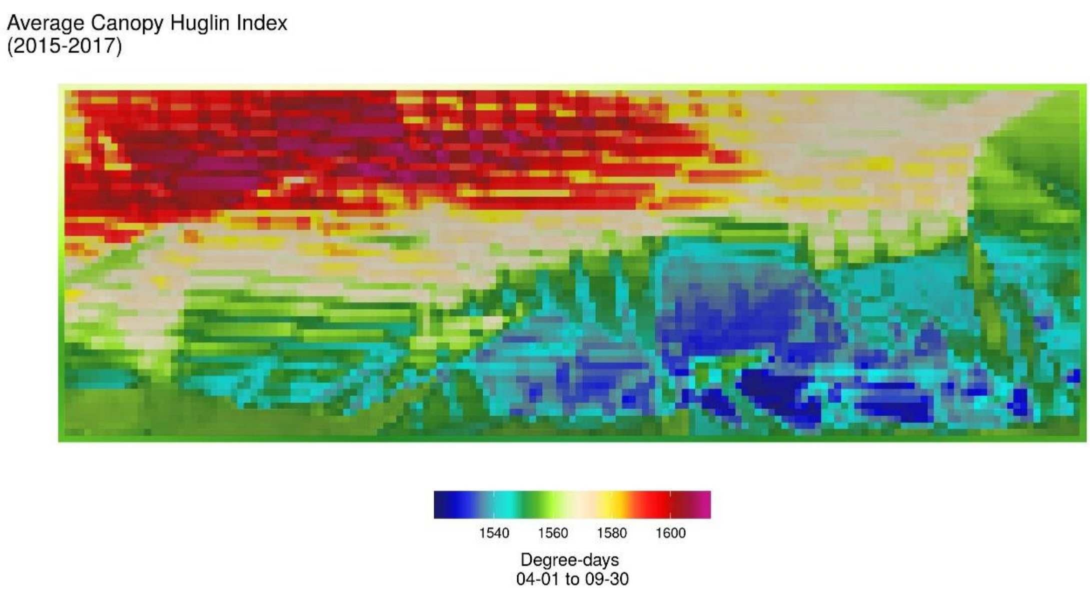


Figure 12: Spatial distribution of the average Canopy Winkler and Canopy Huglin Indices (2012-2017)

1.3 Grapevine response to spatial temperature variability

Phenological stage	Year	Earliest date	Latest date	In-year variability (days)
Budburst	2015	26 April	29 April	3
	2016	6 May	6 May	0
Flowering	2015	3 July	8 July	5
	2016	7 July	12 July	5
Veraison	2015	17 Sept	20 Sept	3
	2016	16 Sept	19 Sept	3

Table 4: dates of phenological events for the five Pinot Meunier temperature sensor sites at Rock Lodge vineyard in 2015 and 2016

The dates of phenological events were monitored on five plots of Pinot Meunier during 2015 and 2016 (2017 is not included because of frost damage). These results (Table 4) show little difference between the two vintages. Budburst is earlier in 2015, but the difference in dates is not significant for veraison, later in the year. The consistently greater in-year variability for flowering, as compared with the other phenological stages, is of interest.

The Grapevine Flowering–Veraison (GFV) model is a linear temperature summation methodology (Parker et al., 2011; Parker et al., 2013) which sums the temperature degrees exceeding 0°C for a range of grapevine varieties starting from the 60th day of the year up to the blooming (F) and to the veraison (V). The original parameterisation of this model offers robustness, especially when testing its response to temperature variations (Parker et al., 2011). For this reason, the GFV is used in the ADVICLIM project to elaborate the forecasts for grapevine flowering and veraison in the perspective of the climatic change.

GFV values for the Pinot Meunier parcels on the Rock Lodge site were calculated for 2015 and 2016. According to our data, the F (flowering) value for the Pinot Meunier variety is 1479 degree days (DD) while the V (veraison) is 2764 (Table 5). The multiannual average of Flowering corresponds to 189th day of the year (July 7th), while the multiannual average of V corresponds to the 262nd (September 18th).

Table 5: The GFV values for the Pinot Meunier variety for 2015 and 2016

	Years	Min GFV value	Average GFV value	Max GFV value	Difference
Flowering	2015	1430	1460	1531	101
	2016	1440	1498	1583	143
	Average	1435	1479	1557	122
Veraison	2015	2565	2703	2810	245
	2016	2689	2825	2941	252
	Average	2627	2764	2876	249

The Flowering and veraison values show an important intra-annual variability with a difference of 122 DD for flowering and 249 DD for veraison (Table 5). The inter-annual variability for flowering is smaller (15 for minimum GFV values, 38 for average, and 42 for maximum), than that for veraison (24 for minimum, 122 for average, 131 for maximum). This may be due to a variance in yield levels over the years.

Conclusion part 1

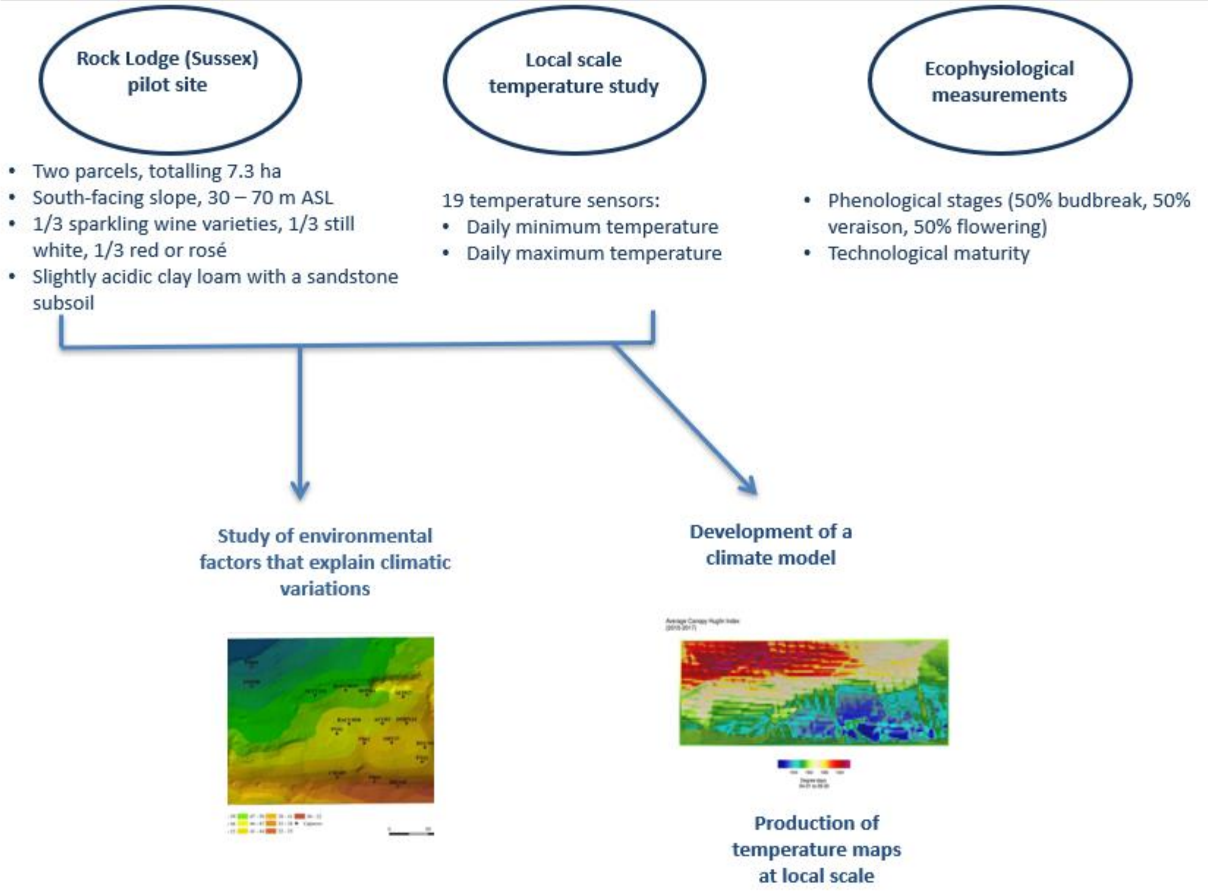
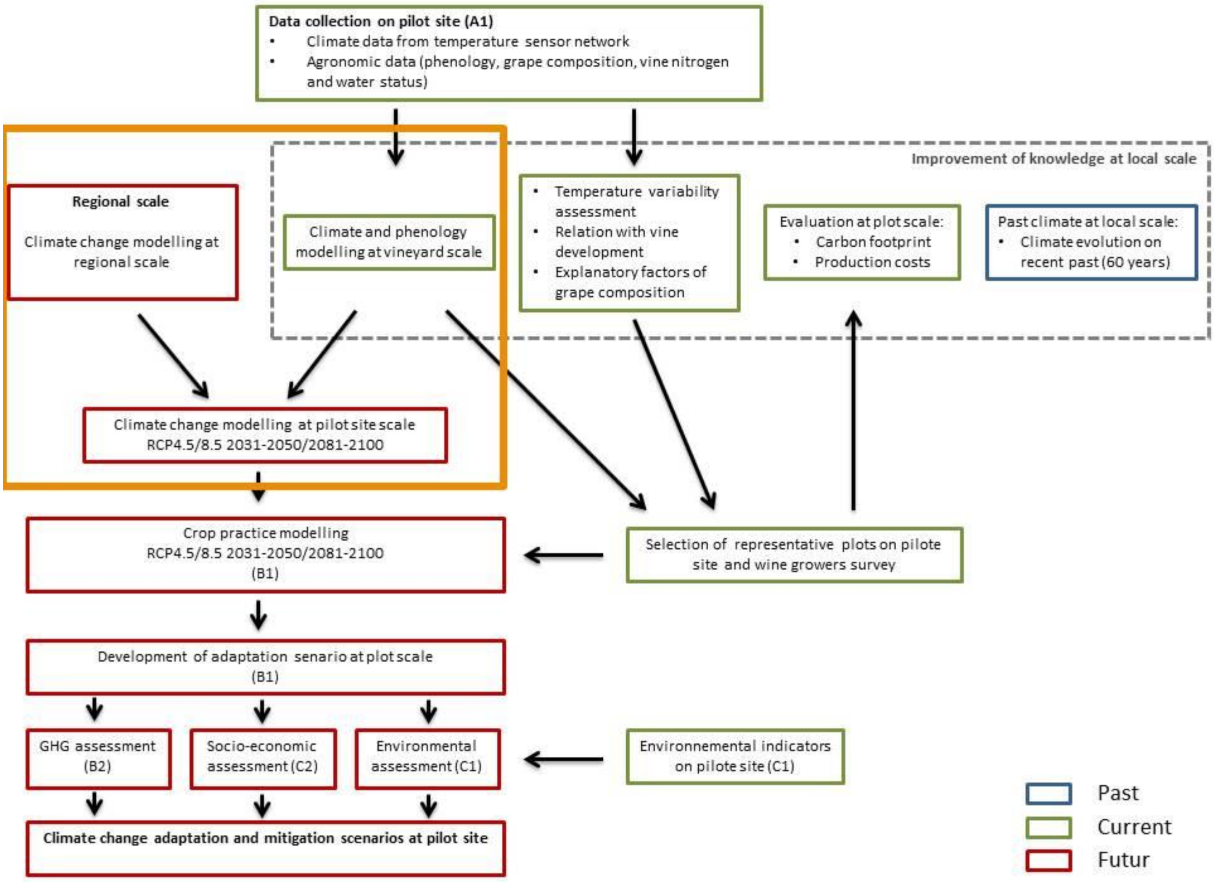


Figure 13: Schematic representation of Part 1 of this report

This innovative study, in such a small area, illustrates the significant temperature range that was found on this pilot site, and enables a greater understanding of the terroir's potential. The bioclimatic indices and phenological maps allow us to visualise the climatic variability over this site and their consequences on grapevine development.

These results are valuable decision support tools, enabling vinegrowers to better adapt plant material and vineyard management practices to terroir components. The models generated from this part of the report will be used to generate maps of climate change at field level.

PART 2: MODELLING OF CLIMATE CHANGE EFFECTS AT THE VINEYARD SCALE



The first part of this report investigated the current climate and its influence on vine development and grape composition; climate and phenological models were developed. In this second part, climate indicators will be calculated from Eurocordex data at the regional scale. The period 1986 to 2005 was studied as a reference, and periods 2031 to 2050 and 2081 to 2100 were studied, using the climate scenarios RCP 4.5 and RCP 8.5, in order to predict any changes. By coupling the climate change data at a regional scale to the climate and phenological models developed at a local scale, map temperature at vineyard scale in link with vine development became possible.

2.1 Regional approach to climate change modelling

Future climate data was analysed for the ADVICLIM trial sites using data from Eurocordex. Daily temperature data was extrapolated from RCP 4.5 and RCP 8.5 scenarios over the period 2020-2100. The Huglin index was calculated for each of these years, and subsequently averaged out over the periods 2031-2050 and 2081-2100 (Figure 14).

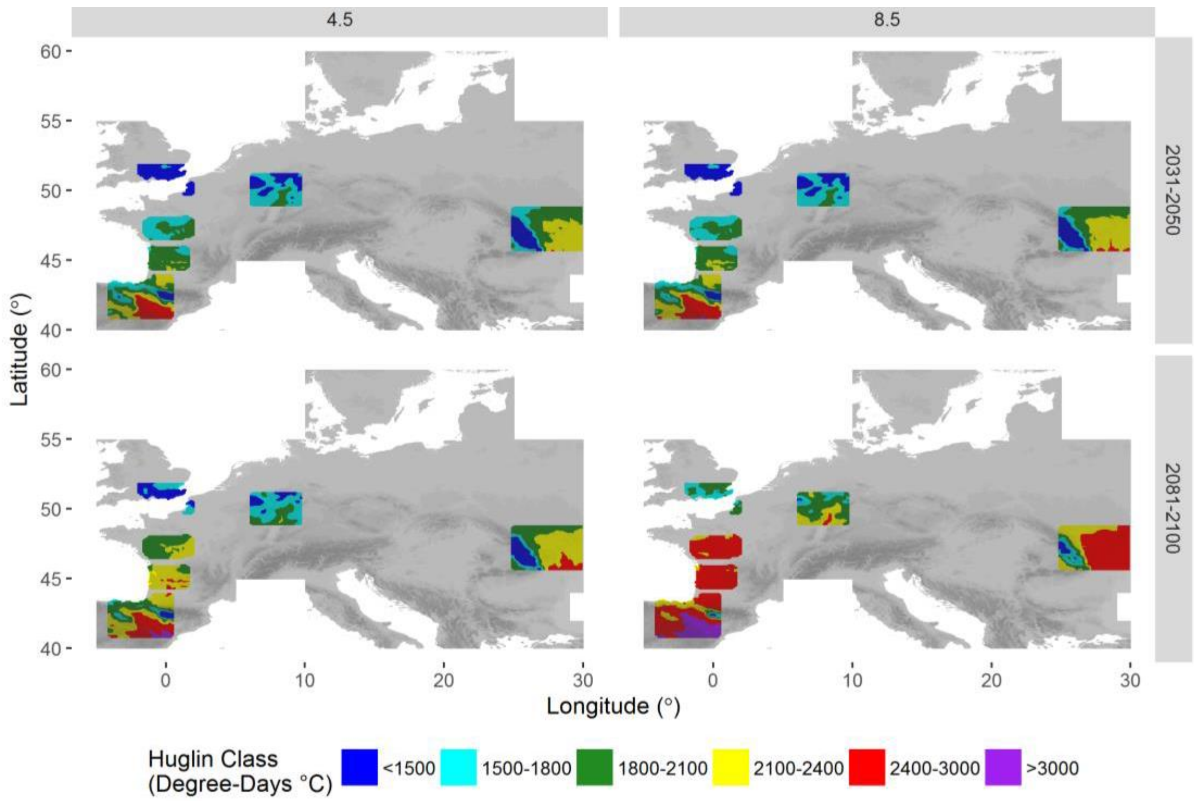


Figure 14: Expected changes in the Huglin Index for the period 2031 to 2050 and 2081 to 2100 according to the climate scenarios of RCP 4.5 and RCP 8.5. (Data source: EURO-CORDEX, R. Vautard).

2.2 Vineyard scale approach to climate change modelling

In order to downscale the regional climate change model to the pilot site scale, the geostatistical model outlined in the previous part of this report was combined with regionalised climate change data generated by Eurocordex. Daily minimum and maximum temperature maps, at the pilot site scale, for both RCP 4.5 and RCP 8.5 scenarios for the period 2081-2100, were generated.

Using this data, the bioclimatic indices investigated above were calculated, and mapped at the scale of the pilot site in the medium and long term. Figure 15 represents the evolution of the Huglin Index, comparing the historical period 1986-2005 in the Plumpton pilot site to future periods and scenarios (Le Roux et al., 2018).

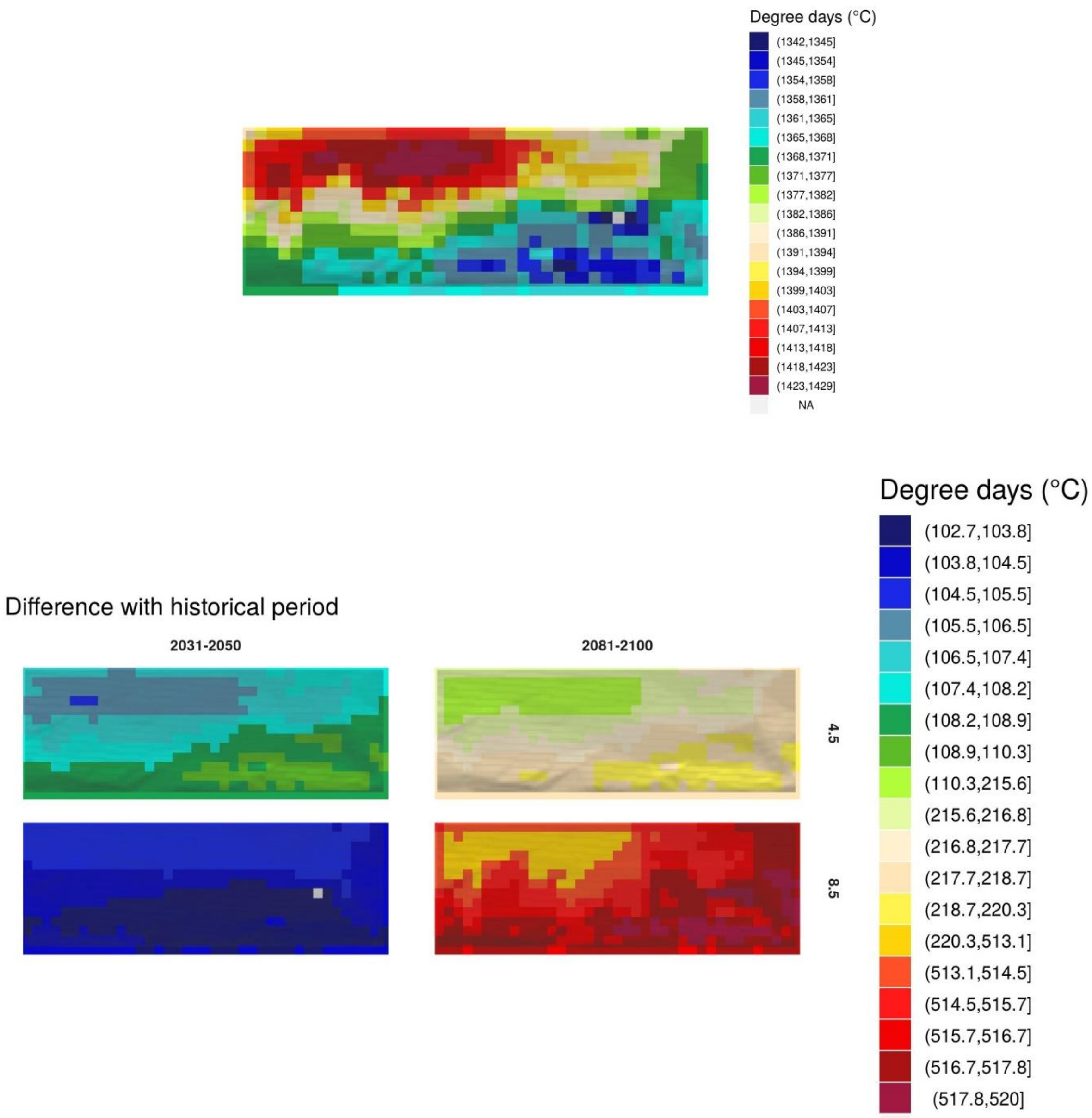


Figure 15: Maps of Huglin Index the Rock Lodge pilot site for the period 1986 to 2005 (a) and expected changes in the Huglin Index (b) for the period 2031 to 2050 and 2081 to 2100 according to the climate scenarios RCP 4.5 and RCP 8.5.

These results indicate that the relative spatial distribution of the Huglin Index remains roughly the same, whichever scenario is deployed. The warmest areas (at the top of the slopes) will remain the warmest, and the coldest areas remain the lower lying areas to the South. However, the warming effect of climate change is greater on lower areas compared to the tops of the slopes. This difference can be explained by the expectation of a greater increase in the minimum, as opposed to the maximum, temperature in the next century. This will lead to a reduction in the overall temperature spatial variability on the study site, and therefore to a reduction in the difference in timing between phenological stages from one vineyard to another. During the historical period (1986-2005), the difference between the coolest and the warmest areas was around 80 degree-days (Table 3); this variance will be the same at the end of the century.

2.3 Phenology modelling at the vineyard scale in a climate change context

To evaluate the impact of climate change on vine development, maps of projected phenology (flowering and veraison) were created at the local scale (Figures 15 and 16) for Pinot Meunier, one of the major grape varieties in the area.

The historical maps (1986-2005) of flowering and veraison highlight the strong link between temperature (as measured by bioclimatic indices) and the timing of phenological stages. The phenologically advanced areas (on the top of the south-facing slope) are those with the higher bioclimatic indices (Figures 15). During the historical period, the spatial range in the timing of phenological events is 5 days for flowering and 3 days for veraison, with the mean mid-flowering period being around the 8th of July, and mid-veraison around the 18th September (Table 3).

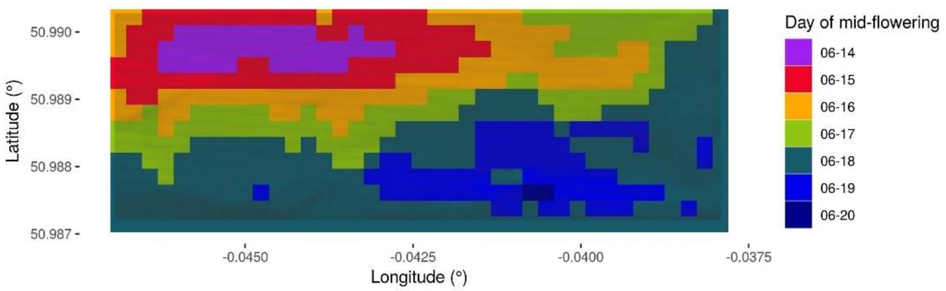


Figure 15: Theoretical mapping of mid-flowering for Pinot Meunier vines at the Rock Lodge site calculated from GFV values over the period 1986 – 2005.

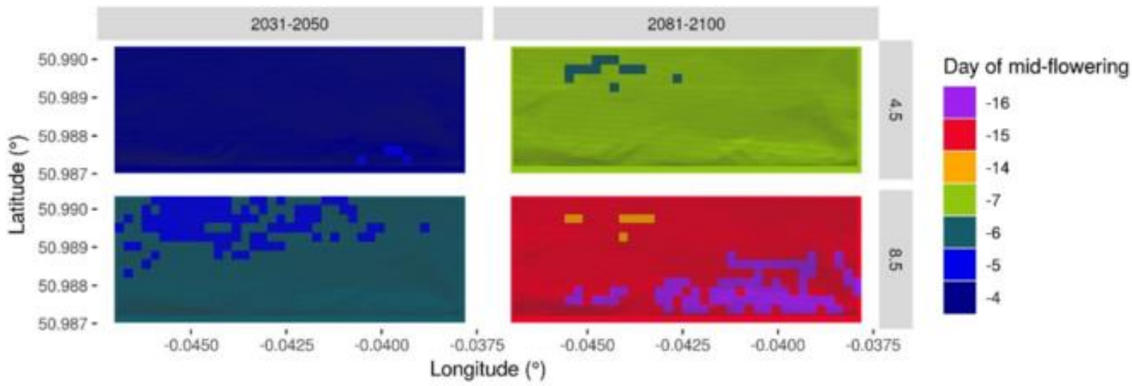
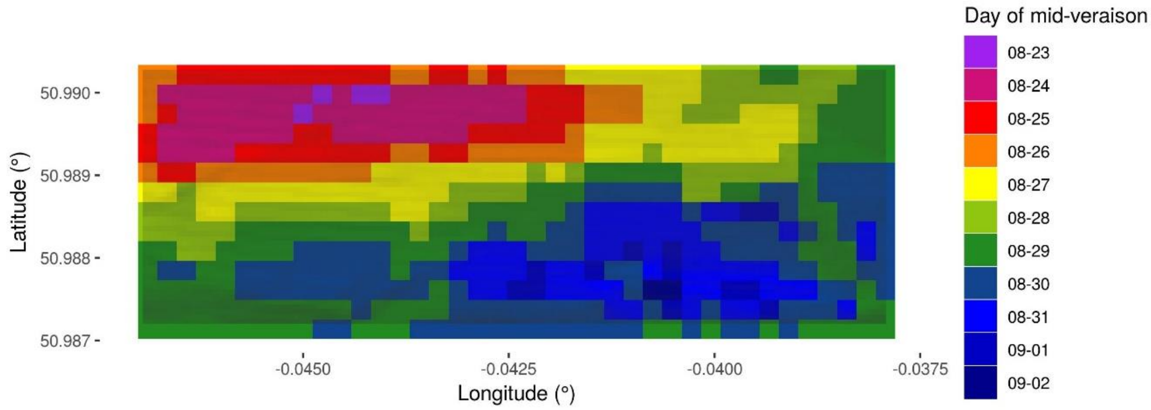


Figure 16: GFV modelling of the changes in the timing of the mid-flowering of Pinot Meunier on the Rock Lodge vineyard plot in 2031-2050 and 2081-2100, according to scenarios RCP 4.5 and RCP 8.5, relative to the historical period 1986-2005

Figure 16 (above) illustrates that there will be little significant change in the date of mid-flowering in the RCP 4.5 scenario of 2031-50, but that flowering will occur a week earlier in 2081- 2100 for the 4.5 scenario, and two weeks earlier for the 8.5 scenario. As expected, the greatest decrease will be in the cooler, low-lying areas.



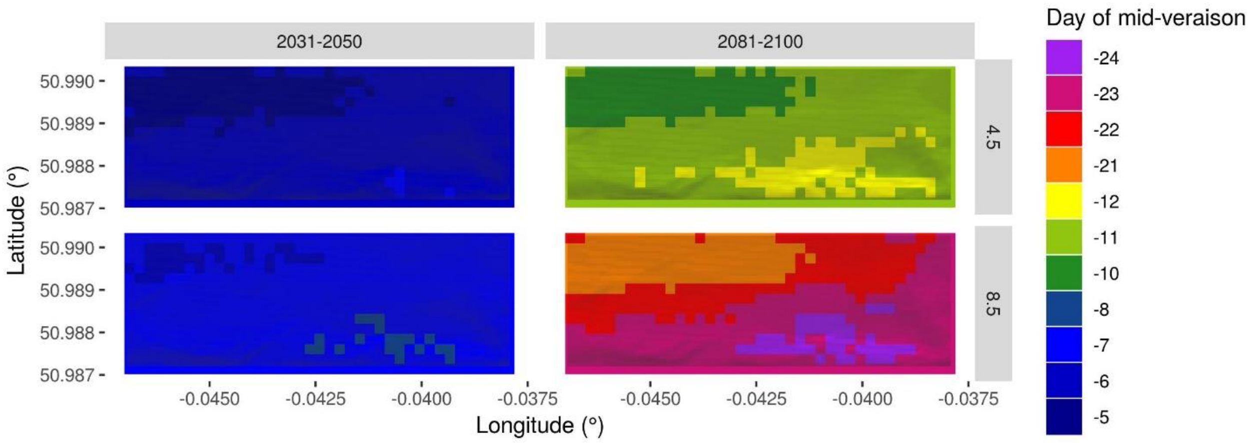


Figure 17: GFV modelling of the changes in the timing of the mid-veraison of Pinot Meunier in the Rock Lodge vineyard plot in 2031-2050 and 2081-2100, according to scenarios RCP 4.5 and RCP 8.5, relative to the historical period 1986-2005

Figure 17 (above) shows that the GFV model predicts a similar trend for mid-veraison as that displayed for mid-flowering, but the differences in timescales are considerably greater. For the 2018-2100 period, the IPC4.5 scenario shows that mid-veraison will be around 11 days earlier, whereas it will be at least three weeks earlier for the 8.5 scenario. As for mid-flowering, the cooler, lower-lying area will suffer a greater change than the upper, warmer area, thus reducing the variability within the site.

The effect of earlier flowering and veraison events will undoubtedly cause earlier fruit ripening, which will be beneficial in Rock Lodge's marginal viticultural climate.

Conclusion part 2

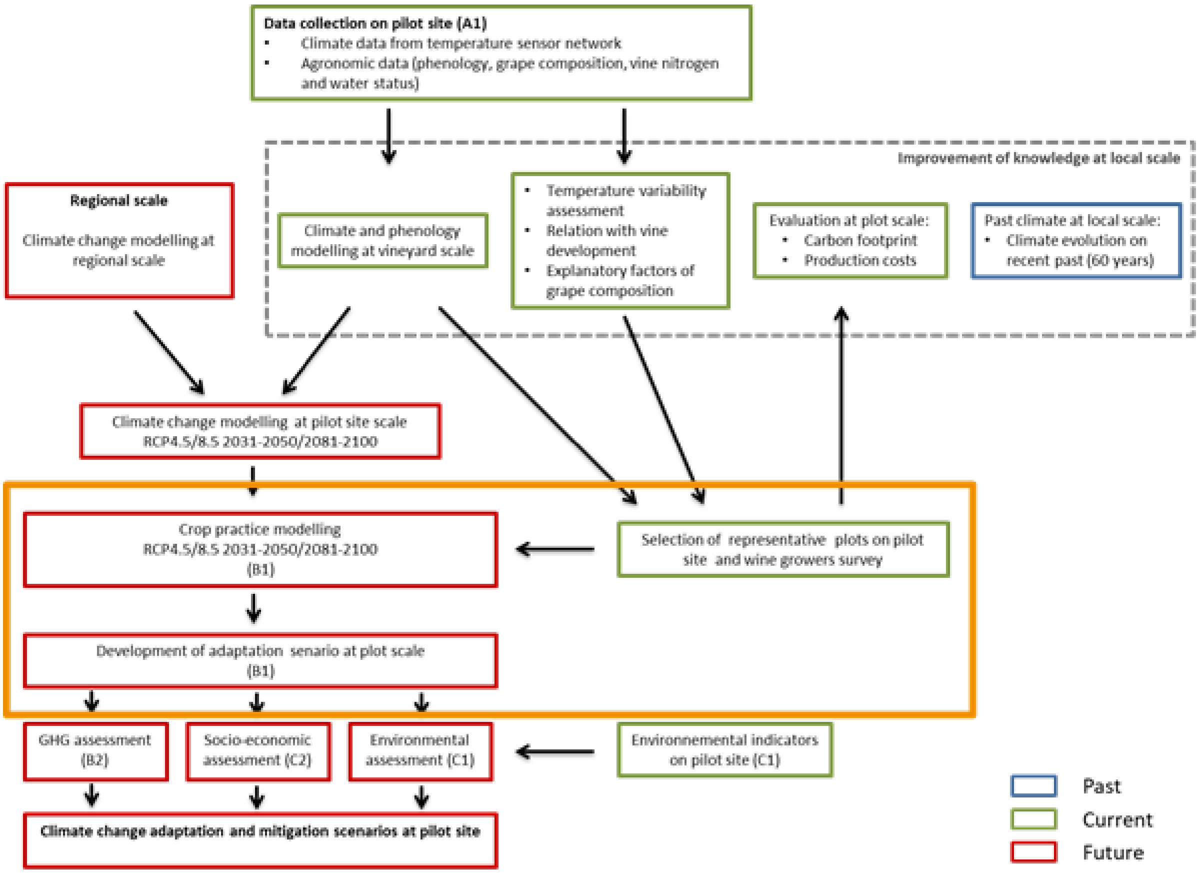
One of the major results of this part of the report is to demonstrate the feasibility of mapping the evolution of climate change and the consequences on vine development at the vineyard scale.

These results indicate that, according to this prediction method, the relative spatial distribution of temperatures on the pilot site will not be modified, whichever scenario or period is used. However, a reduction of the spatial amplitude of climatic indices will be observed, compared to the reference period, due to a greater increase in maximum temperatures, compared to minimum temperatures.

The model does not demonstrate a very significant difference between the two scenarios (4.5 and 8.5) in the near future (2031-2050). However, in the longer term (2081-2100), there is a strong difference between the two scenarios, with important consequence on vine development.

The next step will be to evaluate the consequences of climate change on cultural practices, by using selected plots, which are representative of this pilot site in terms of environment, climate, wine production and cultural practices.

PART 3: ADAPTATION OF CULTURAL PRACTICES TO CLIMATE CHANGE



This part of the report deals with crop husbandry modelling and the development of climate change adaptation practices at the vineyard plot scale.
The crop management practices implemented in 2016 were identified for the Rock Lodge pilot site, then the effects of climate change on these practices was investigated.

3.1 Characteristics of the Rock Lodge vineyard site

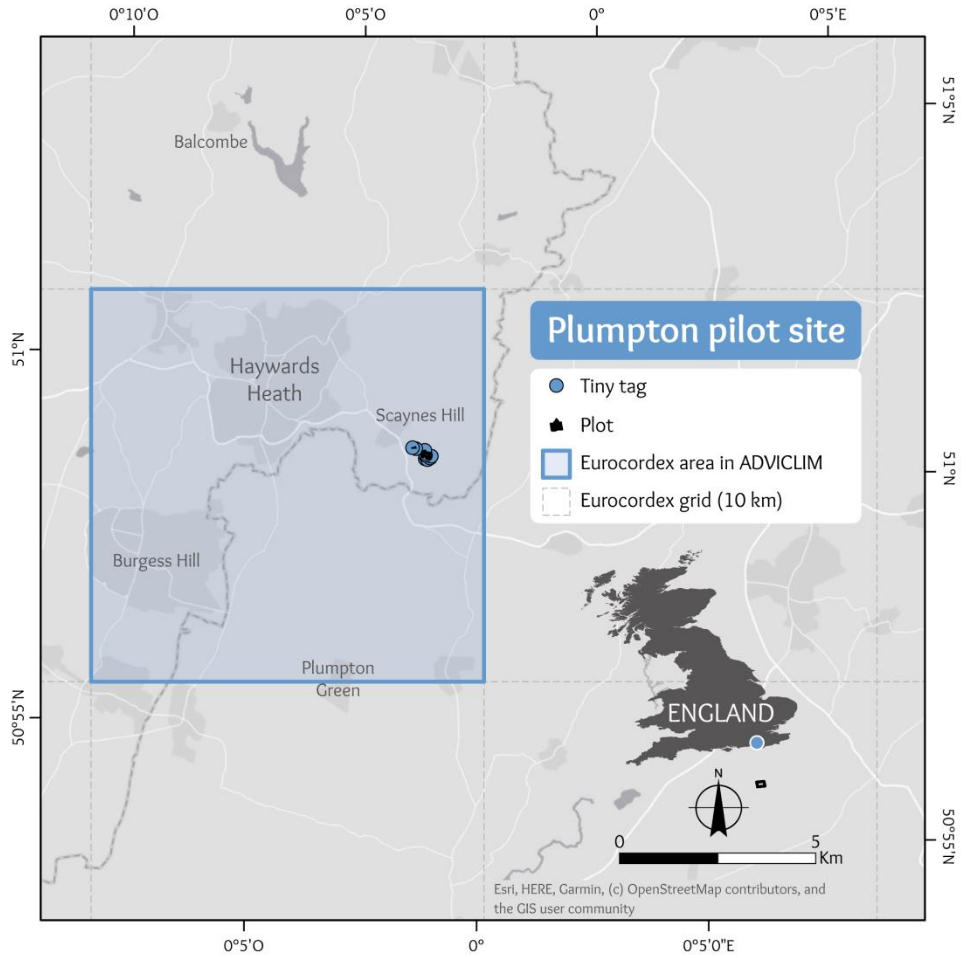


Figure 18: Location of the Rock Lodge vineyard site (managed by Plumpton College)

Total surface area	7.3 ha in total (2.3 + 5)
Elevation	30 – 70 m ASL
Orientation	South-facing
Surrounding area	Woodland
Soil type	Acid clay over sandstone
Grape varieties	1/3 Champagne varieties: Pinot noir, P. Meunier, Chardonnay 1/3 black varieties: Dornfelder, Rondo, Acolon, Pinot noir (Burgundy clones) 1/3 other whites: Bacchus, Riesling, Regner, Pinot Blanc, Ortega
Vine spacing	1.2 m between vines x 2.2 m wide alleys
Training system	Vertical shoot positioning (VSP)
Pruning system	Double Guyot
Vineyard floor management	Rough pasture in alleys and headlands Mostly herbicide under-row, but some mowing and cultivation
Conventional / organic	Conventional
Manual operations	Winter pruning, excess bud/shoot removal, tucking in, leaf stripping, harvest, trellis repairs
Mechanical operations	Mowing, spraying, trimming, fertiliser application
Labour input	One vineyard manager, one apprentice, plus students learning their trade.

Table 6: Characteristics of the Rock Lodge vineyard plot

The Vineyard Manager was interviewed using the ADVIClim questionnaire Q3. All interventions with tools, inputs and equipment carried out in 2016 were recorded.

3.2 Application of the SEVE model

In order to assess potential future adaptation trends, a specific prototype of the SEVE (Simulating Environmental impacts on Viticultural Ecosystems) model was implemented. The baseline of the SEVE model was adapted to local constraints, and the agronomic characteristics of the Rock Lodge vineyard. Simulated results were viewed using the graphical user interface, and through the *postgresl/postgis* database coupled with the SEVE model.

In the first instance, the data on the evolution of the phenological stage timings was analysed to evaluate the differences between the two time periods, 2031-2050 and 2081-2100. This analysis, some of which is shown in Table 7, estimates the minimum, median and maximum dates when the model predicts that the grape berries will reach a concentration of 200g/l of sugar for each climate change scenario.

Significant changes can be noticed, in particular an earlier maturation of the grapevine berries in the later periods, especially during the period 2081-2100 for the scenario 8.5. The model predicts that, by 2050, all harvest will be complete by the third week in October, even the Riesling, which has never successfully ripened to date. It is worth noting, that, in the UK, Chardonnay, Pinot noir and Pinot Meunier is used to produce sparkling wine, and so is often harvested before the berries reach 200 g/l of sugar. The differences in ripening dates between the 4.5 and 8.5 scenarios for the 2031-50 period are not significant, but they certainly are for the 2081 –2100 period. By this time, the model predicts that all the berries will reach maturity by the 10th October for the 4.5 scenario, and by the 21 September for the 8.5 scenario, with some harvests starting in mid-August!

Table 7: Differences of theoretical maturity (200g/L of sugar) date between representative plots of Plumpton pilot site

2031-50 period

Variety	IPC scenario	Dates at which maturity is reached		
		earliest	median	latest
Bacchus	4.5	15 Sep	20 Sep	28 Sep
Bacchus	8.5	7 Sep	20 Sep	30 Sep
Chardonnay	4.5	2 Oct	7 Oct	18 Oct
Chardonnay	8.5	22 Sep	8 Oct	18 Oct
Pinot Blanc	4.5	14 Sep	19 Sep	28 Sep
Pinot Blanc	8.5	7 Sep	19 Sep	30 Sep
Pinot Meunier	4.5	21 Sep	26 Sep	5 Oct
Pinot Meunier	8.5	13 Sep	26 Sep	7 Oct
Pinot Noir	4.5	30 Sep	4 Oct	14 Oct
Pinot Noir	8.5	20 Sep	5 Oct	15 Oct
Riesling	4.5	4 Oct	9 Oct	20 Oct
Riesling	8.5	24 Sep	10 Oct	21 Oct

Seyval blanc	4.5	18 Sep	24 Sep	2 Oct
Seyval blanc	8.5	10 Sep	23 Sep	4 Oct

2081-2100 period

Variety	IPC scenario	Dates at which maturity is reached earliest	median	latest
Bacchus	4.5	3 Sep	12 Sep	22 Sep
Bacchus	8.5	16 Aug	27 Aug	6 Sep
Chardonnay	4.5	20 Sep	29 Sep	8 Oct
Chardonnay	8.5	29 Aug	9 Sep	20 Sep
Pinot Blanc	4.5	3 Sep	12 Sep	21 Sep
Pinot Blanc	8.5	16 Aug	27 Aug	6 Sep
Pinot Meunier	4.5	1 Sep	14 Sep	27 Sep
Pinot Meunier	8.5	15 Aug	29 Aug	11 Sep
Pinot Noir	4.5	17 Sep	28 Sep	7 Oct
Pinot Noir	8.5	27 Aug	8 Sep	19 Sep
Riesling	4.5	22 Sep	1 Oct	10 Oct
Riesling	8.5	30 Aug	10 Sep	21 Sep
Seyval	4.5	7 Sep	16 Sep	24 Sep
Seyval	8.5	19 Aug	30 Aug	8 Sep

The SEVE model was then used to predict changes in viticultural practices over the different periods, applying the two IPC scenarios. The results recommend only minor changes in these operations, despite significant differences in the timings of phenological events. For instance, it is unlikely that vineyards will need to be irrigated in Sussex by 2100. However, the SEVE model results recommend a slight increase in the number of pesticide applications, for both scenarios, in response to an increase in disease pressure caused by an increase in temperature and relative humidity increasing the potential number of fungal generations in the growing season.

Table 8: evolution of the mean number of fungicide treatments on four varieties in the Rock Lodge site according to the 4 scenarios tested. All these received 8 applications in 2016.

Varieties	**2030-2050 period**		**2080-2100 period**	
	RCP 4.5	**RCP 8.5**	**RCP 4.5**	**RCP8.5**
Bacchus	9	9	9	9
Chardonnay	10	10	10	9
Pinot noir	10	10	9	9
Pinot Meunier	9	9	9	9

Potential vineyard adaptation scenarios include the following:

<u>Short term</u>

Vine canopy — Control the level of fruit exposure, by moderating leaf removal to conserve cool ripening conditions to synchronise ripening and avoid sunburn on the grapes.
Trim the canopy more regularly, to reduce hydrological stress and evapotranspiration (due to more important solar radiation and higher

	temperature) on the grapevines.
Vineyard floor	Monitor and resolve soil compaction issues in order to reduce surface water run-off, which can cause flooding in the vineyard.
	Continue to grow green cover (cover crops) to keep the soil surface cool and humid.
	Respond more flexibly to extreme weather events, for instance, close mowing, or even destruction of green cover when the risk of frost or drought arises.
Frost	Adapt or delay pruning in frost-prone areas
	Invest in frost control measures, such as water sprinkler and heating systems.
Vineyard operations	Maintain high yields in order to delay ripening.
	Harvest earlier (mid-September, rather than mid-October)

<u>Medium term</u>

Grape varieties	Monitor more closely the variations in climate within the field and planting more suitable grape clones and varieties.
	Conversion of grape varieties in the field by top grafting.
	Select rootstocks that are more water-efficient and drought-tolerant.
Vineyard floor	Select most appropriate green cover for vineyard floor, rather than planting grass, or just allowing native vegetation to grow.
Vineyard operations	Monitor and manage new pests, such as grapevine moths and spider mites.

<u>Long term</u>

Vineyard siting	Plant grapevines at higher altitudes and on slopes facing west or east in order to moderate the high levels of solar radiation on south-facing slopes.
	Plant vineyards nearer the coast, to moderate temperatures and avoid frost risk.
Grape varieties	Introduce new grape varieties more suitable for the climate, producing still wines.
Training system	Reduce total canopy height to control evapotranspiration in the field.
	Use more sprawling training systems that protect the crop from sunburn.
Vineyard operations	Harvest earlier, and at night
	Develop effective integrated pest management systems to manage increased pest pressure
Irrigation	Install water capture and irrigation/water sprinkling systems to manage drought and frost events.

These potential adaptations were implemented in the SEVE model as decision rules; for example, changes in training systems can be used as long as the limit of vine variety adaptation is not reached. Regarding adaptation through the choice of plant material, the threshold for the date of replacement of a grape variety was set at 4 years out of 10 where the theoretical maturity (200 g/l sugar) was being reached before the 23rd August. Table 9 shows the recommendations (according to the SEVE model) for the conversion of grape varieties for the Rock Lodge test plot, according to different time periods and scenarios.
No changes of grape variety are needed for the mid-term period (2031-2050).

Table 9: vine varietal changes recommended on the Rock Lodge plot to adapt to the IPC 8.5 scenario

Current grape variety	Limit date	Potential replacement grape variety
Bacchus	2085	Sauvignon blanc
Dornfelder	2084	Gamay
Pinot noir	2098	Syrah
Pinot Meunier	2084	Cabernet franc

The results provided by WALIS for both periods and both scenarios do not show a significant increase in water stress. Consequently, the need to use irrigation to control water stress is not confirmed. However, this factor needs further investigation, due to the limitations in the accuracy of rainfall data provided at regional scale by the climate models.

According the results provided by the SEVE model, the main adaptation strategies could focus in the short term on winemaking techniques, and in the medium/long term on the change of grapevine variety, so as to delay the phenological cycle and avoid a very early maturity. Water deficit does not seem to increase but this point needs further investigation.

The model evaluated frost risk occurrence in the future, when negative temperature are consistently indicated post-budburst. There was no indication of an increase in frost risk in the 2030-50 period for either IPC scenarios, but the risk increased very significantly for the 2080 – 2100 period and IPC 8.5 scenario; for all currently planted varieties, particularly Bacchus, Chardonnay, Dornfelder, Pinot blanc, Pinot noir, Pinot Meunier and Riesling.

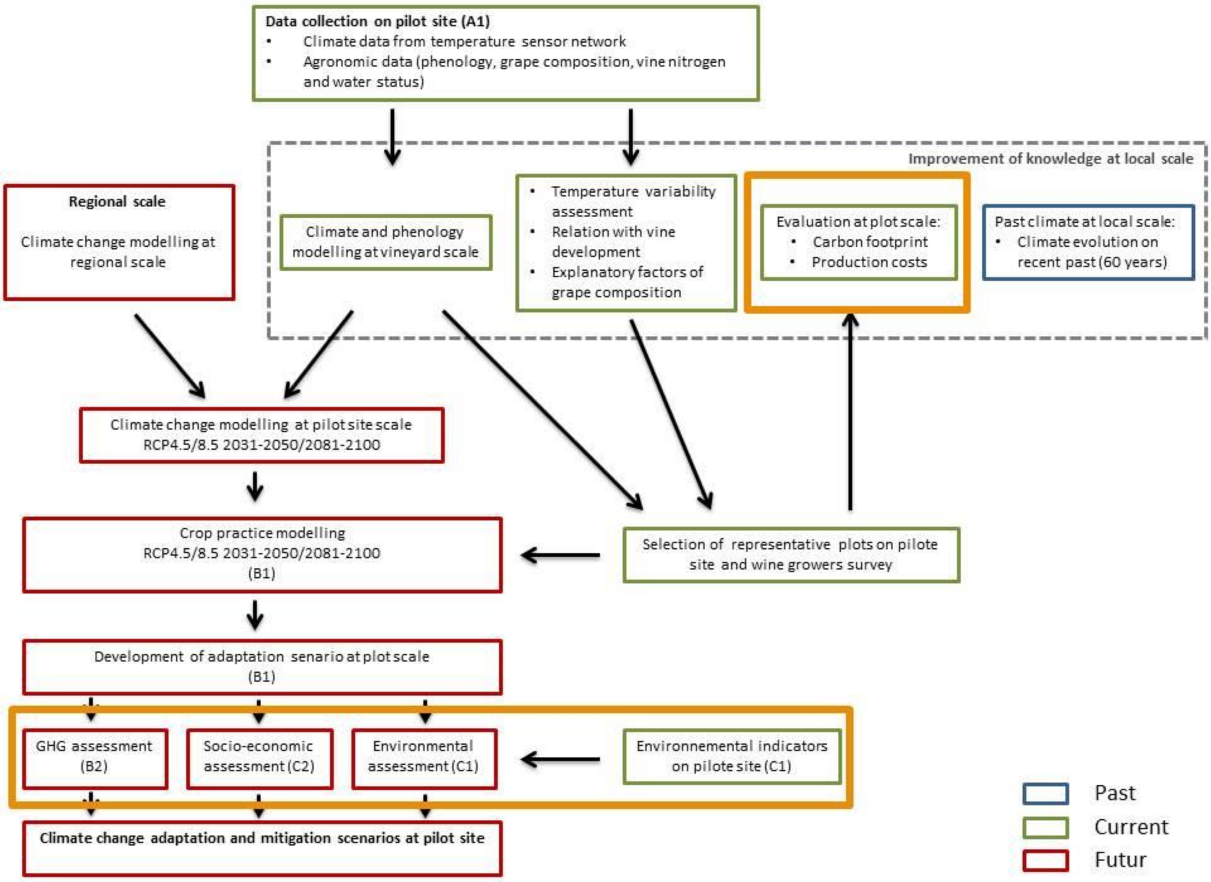
Conclusion to part 3:

The key findings are:

- There are very few changes in agronomic interventions needed during the first time period (2031-2050). In the second period (2081-2100), there is a need for an increase in the number of pesticide treatments for 80% of the representative plots.
- The recommended climate change adaptation strategies are the change in grapevine variety in the first and the second period.
- The water deficit values generated by the WALIS model do not reach a level which justifies the implementation of irrigation at any time and in any scenario.

Data provided by regional climate models, such as rainfall or humidity, must also be aggregated in order to evaluate changes in specific agronomic interventions and adaptation strategies at the plot scale.

PART 4: ASSESSMENT OF THE SUSTAINABILITY OF CURRENT AND FUTURE VITICULTURAL PRACTICES



The preceding part of this report investigated the evolution of viticultural practices on the Rock Lodge pilot site and different viticultural adaptation scenarios. These changes can affect the environmental footprint and the socio-economic condition of vinegrowers. The potential impact of these scenarios on the environment and on production costs are discussed in this part of the report. The current environmental indicators at pilot site scale were defined, and the level of greenhouse gas (GHG) emissions and the costs of changes in viticultural practices were calculated. The objective of this part of the report is to inform vinegrowers on the sustainability of their practices, both at the current time and in the future.

4.1 Greenhouse gas emissions

The objective of this section is to evaluate GHG emissions for each viticultural practice on the Rock Lodge pilot site, based on cultural practices implemented in 2016. GHG emission assessment provides information to the vinegrower on the environmental impact of their practices and enables them to evaluate potential mitigation strategies.

For the calculation of the current GHG emissions, it was assumed that the whole of the Plumpton College Rock Lodge site was managed in the same way, whatever the planted variety. The GHG emission calculation methodology was applied to the 2016 season, on the vineyard operations listed for Action B2 of this project. The objective was to identify the most emitting management strategies and vineyard operations, and the major types of emissions.

The main vineyard operations were grouped as follows:

- Winter pruning: cutting, tying down and burning and mulching of prunings
- Trellis management and maintenance: erection of new trellis and replacement of broken wires, posts and end-assemblies on established trellis
- Soil management: vineyard floor maintenance (mowing, cultivation, herbicides, in both headlands, alley and under-row area
- Canopy management: excess bud & shoot removal, tucking in, trimming, leaf stripping.

As can be seen from figure 19, the total emission level of the plot is 1800 kg eq CO_2/ha/year, the most emitting types of operation being:

- Pest and disease management (39% of the total emissions)
- Soil maintenance (24%)
- Trellis management (23%).

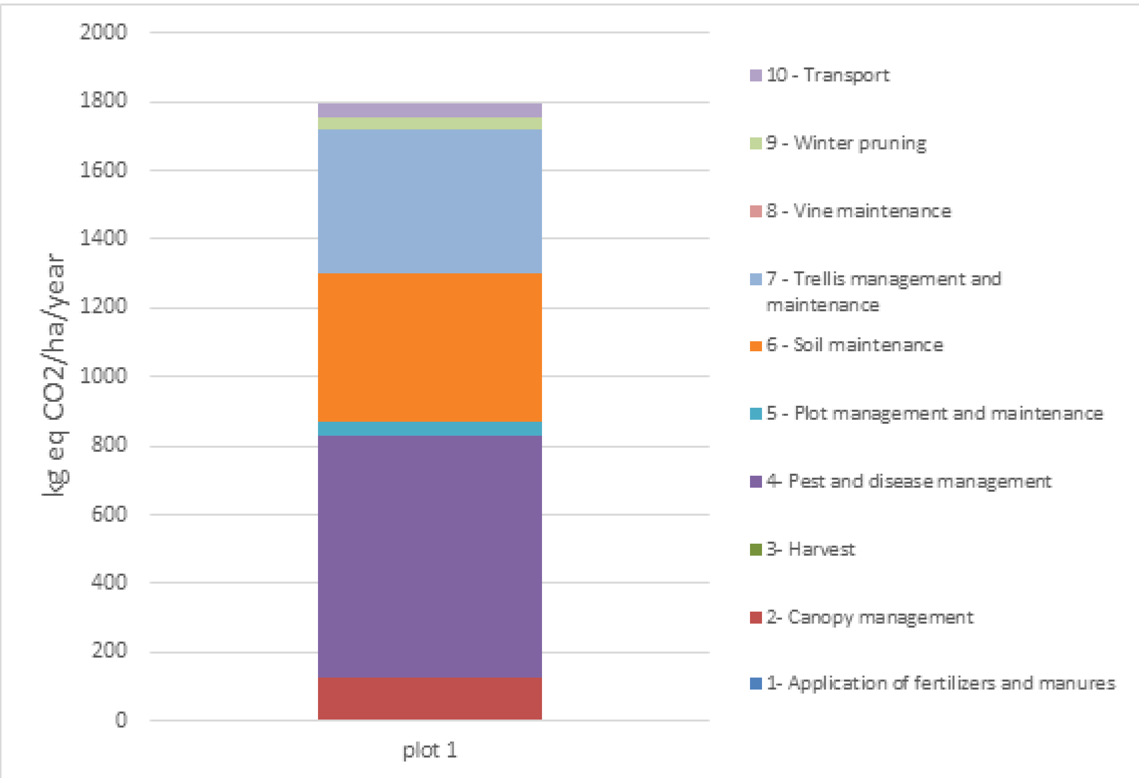


Figure 19: Total GHG emissions for Rock Lodge vineyard, categorised by viticultural operation

These results are largely due to the number of mechanical operations carried out, and the power of the tractor used (70 hp), in particular:

- Pest and disease management: 8 passes
- Soil maintenance: 9 passes

The differences between direct and indirect GHG emissions were calculated for each plot (see Figure 20). Direct emissions are those emitted on the plot and indirect emissions are produced during the extraction of raw materials and the manufacturing of the system elements. In the case of Plumpton, the direct emissions are a bit more important (60%) than indirect emissions.

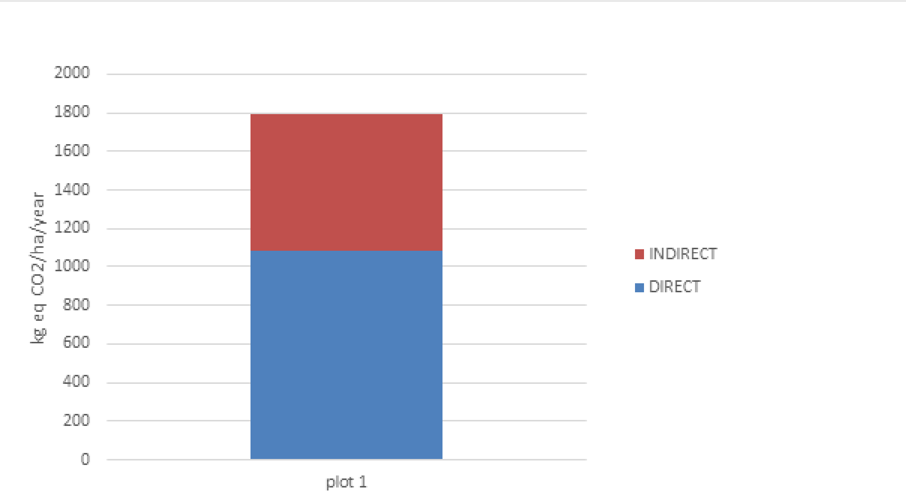


Figure 20: The total direct and indirect emissions for Rock Lodge vineyard

As can be seen in figure 21, the relative of importance of direct and indirect emissions relating to each viticultural operation is similar to the totals.

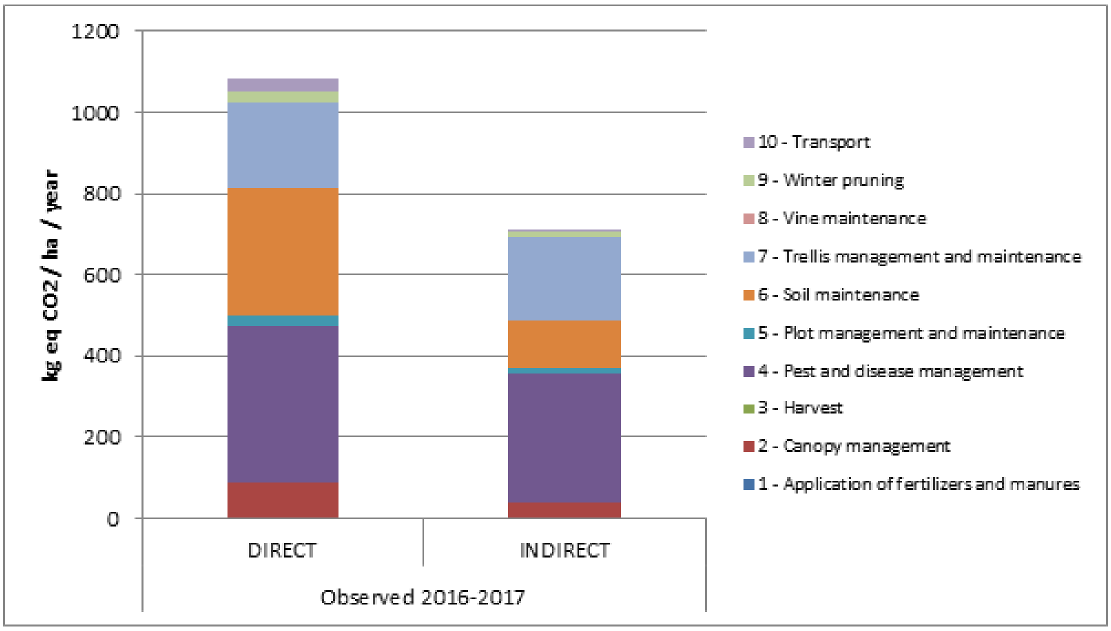


Figure 21: Direct and Indirect GHG emissions by interventions for the Rock Lodge site

The split between direct and indirect emissions depends on the vineyard operation. As metal posts are used in this vineyard, the proportion of indirect emissions generated by trellis management is greater than, for instance, soil maintenance, where very few materials are used to maintain the vineyard floor (apart from a small amount of herbicide).

The SEVE model produced scenarios describing the evolution of cultural practices (date and number of all the interventions in a season), and some of the possible adaptation strategies. GHG emission levels can vary according to changes in tools and equipment and changes in the quantities of inputs used, particularly pesticides, fertilisers and energy (mostly diesel and electricity).

The only significant adaptation strategy that was generated by the simulation models is a slight increase in the number of fungicide treatments, particularly over the period 2081-2100. These changes can have a significant environmental impact due to the high level of GHG emissions induced by fungicide treatment during a year.
It is important to note that these estimations are based on the hypothesis that there is little future progress in plant protection methods. It is very likely that developments in genetically-improved varieties, biological or cultural plant protection methods reduce the overall numbers of pesticide applications in the near future.

4.2 Environmental assessment

Climate change in the UK will lead to wetter, warmer winters, and hotter, drier summers.

Warmer temperatures and an increase in carbon dioxide concentration in the atmosphere will lead to an increase in vine vigour, and thus in grapevine yield, but this effect might be compromised by hydrological stress on the plant, due to the change in rainfall patterns and increased evapotranspiration. Nevertheless, there is a clear indication that the Rock Lodge site will become less marginal for the cultivation of grapevines, and that climate change will result in riper and more regular yields of classic varieties, such as Pinot noir and Chardonnay. The future climatic changes will also increase the frequency of some pest and diseases, particularly late season Botrytis and insect pests.

Climate change is likely to create long-term pressures on water availability in the UK (particularly with increased urbanisation of rural areas), and lead to more extreme weather events, such as floods and droughts. The rainfall pattern over the 21st century is not expected to be uniform over Britain, with the contrasts between wet and dry areas and wet and dry seasons expected to increase. Overall, the UK climate is generally perceived as having moderately high rainfall, with a significant variation of water availability not only from place to place but also from time to time. Water availability from groundwater, rivers, and lakes is mainly controlled by rainfall and evapotranspiration. River- and ground-water levels are at their lowest levels towards the end of the summer and into early autumn.

However, there are competing demands for water, and judgements have to be made on how much water to leave in the natural environment to support wildlife, and recreation.

The vineyard soil texture at Rock Lodge is a silt/clay loam, which is not ideal for water infiltration, so the vineyard is likely to suffer from runoff with heavy precipitation. However, the vineyard is unlikely to suffer from floods, as both fields are sloping, with drainage channels to evacuate surface water at the lowest side. Drought events at Rock Lodge are rare, but possible, particularly as there are areas in the vineyard where the water table is very near the surface, limiting the depth of grapevine root development.

The vineyard requires the application of fertiliser and fungicide to support grapevine growth and produce quality grapes. However, Plumpton's policy is to use these as little as possible in order to minimise their impact on the environment. In the UK, around 60% of nitrates and 25% of phosphorous in water bodies are estimated to have farming origins, and it is thought that 75% of sediments polluting water bodies have derived from the agriculture industry. (Holden, et al, 2015). Although not in a Nitrate Vulnerable Zone, the vineyard is surrounded by ditches and bodies of water, which must be protected from pollution, and any pesticide applications must comply with LERAP (Local Environment Risk Assessment for Pesticides) legislation.

As can be seen in figure 22, agriculture has repeatedly been identified as one of the largest contributors to the loss of biodiversity worldwide (Burns, et al, 2016). The last 50 years of agricultural intensification in Britain had a significant impact on the biodiversity, destroying half of the bird population, butterflies, and wildflowers. It is believed that the main cause of this loss is the use of pesticides that have exterminated more and more insects at the base of the food chain.

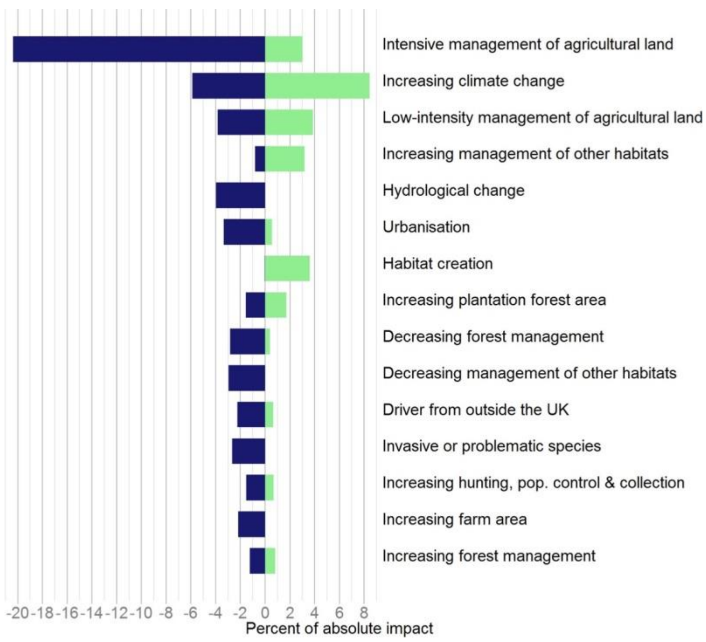


Figure 22: the impact of human activity on insects, plant and vertebrate populations from 1970–2012 in the UK. The green bars represent the positive impact and the blue bars the negative impact (Burns, et al, 2016).

The only fertilisers that are applied to Rock Lodge vineyard are those prescribed by qualified agronomists subsequent to the analysis of soil and vine leaf samples. The vineyard manager deploys an integrated pest management strategy, using a range of cultural plant protection techniques and regular pest monitoring, in order to reduce inputs to a minimum. There are significant areas to the East and South of both fields, which are maintained in a semi-wild state in order to provide food and habitat for wildlife.

The main waste products generated from vineyards is vine prunings (twigs) and berry skins and stalks, which result from the pressing operation in the winery. At Rock Lodge, winter prunings are mulched in the alleys, unless there are clear symptoms of grapevine trunk disease present, in which case they are collected and burnt. Bunch stalks and berry skins are composted, and then used on the College grounds. All pesticide containers are thoroughly rinsed, with the rinsing water poured into the spray tank, prior to disposal.

The soil acidity at Rock Lodge vineyard is low, particularly in Pond Field (average 5.4 for the clay-loamy part and 5.5 for the sand slit loamy part). This soil acidification is mainly caused by acidic precipitation, nutrient uptake by plant roots and mineralisation of organic matter.
This requires testing and liming on an annual basis. The soil organic matter level in Pond Field is also rather low, which increases the risk of compaction and erosion, but this is controlled by the presence of permanent grass cover in the vineyard alleys.

4.3 Socio-economic assessment

The socio-economic impacts of climate change were assessed for the Rock Lodge pilot site, based on a summary of the number of interventions per operation, shown on Table 10. More details on the cost estimation for each viticultural operation, a calculation based on Roby et al (2008), on the selected plots are provided in Figure 4. The total cost of managing the plot is around 4100 Euros/.ha, with canopy management and pruning, the main expenses, both cost around 1150 euros/ha, which represents 28% of the annual cost for maintaining the vineyard. Both these practices are expensive, as they take up a lot of worker time. The cost of machinery used for other interventions, such as fungicide treatments and soil management, is spread over several years.

Table 10: Number of viticultural interventions per operation for the Rock Lodge site in 2016 (e.g. winter pruning = cutting + tying down + mulching)

	n° of interventions
Winter pruning	3
Soil management	9
Vine management	1
Trellis repairs	1
Canopy management	7
Fertiliser application	0
Fungicide application	7
Harvest	1
TOTAL	29

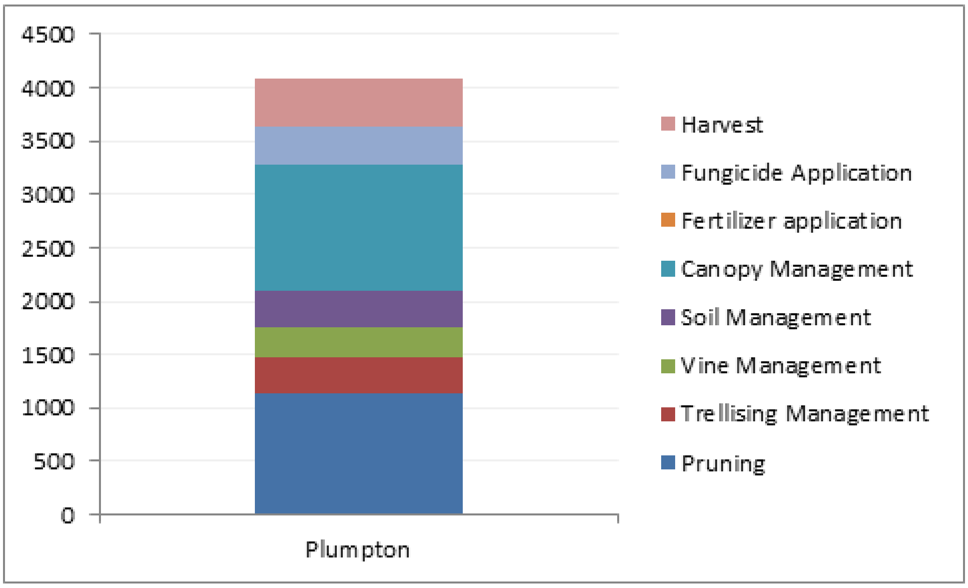


Figure 23: Cost estimation per ha split up by sub-viticultural operations for representative plot in the Rock Lodge pilot site

According to the results generated by the SEVE model in Action B1, the main change in viticultural operations in the future is an increase in the number of fungicide treatments for both scenarios. The model predicts a slight increase, but cannot give a precise value in monetary terms. However, due to the rise in the frequency of atypical weather events, such as warm spells at the end of the winter period, the risk of spring frosts may increase. On the other hand, as the weather warms, the range of grapevine varieties that will successfully ripen at Rock Lodge will increase, allowing the production of red wines from classic varieties (such as Gamay), and a broader range of still whites.

Conclusions for Part 4

The levels of greenhouse (GHG) emissions, environmental indicators and socio-economic conditions were evaluated in order to assess the sustainability of current and future viticultural practices.

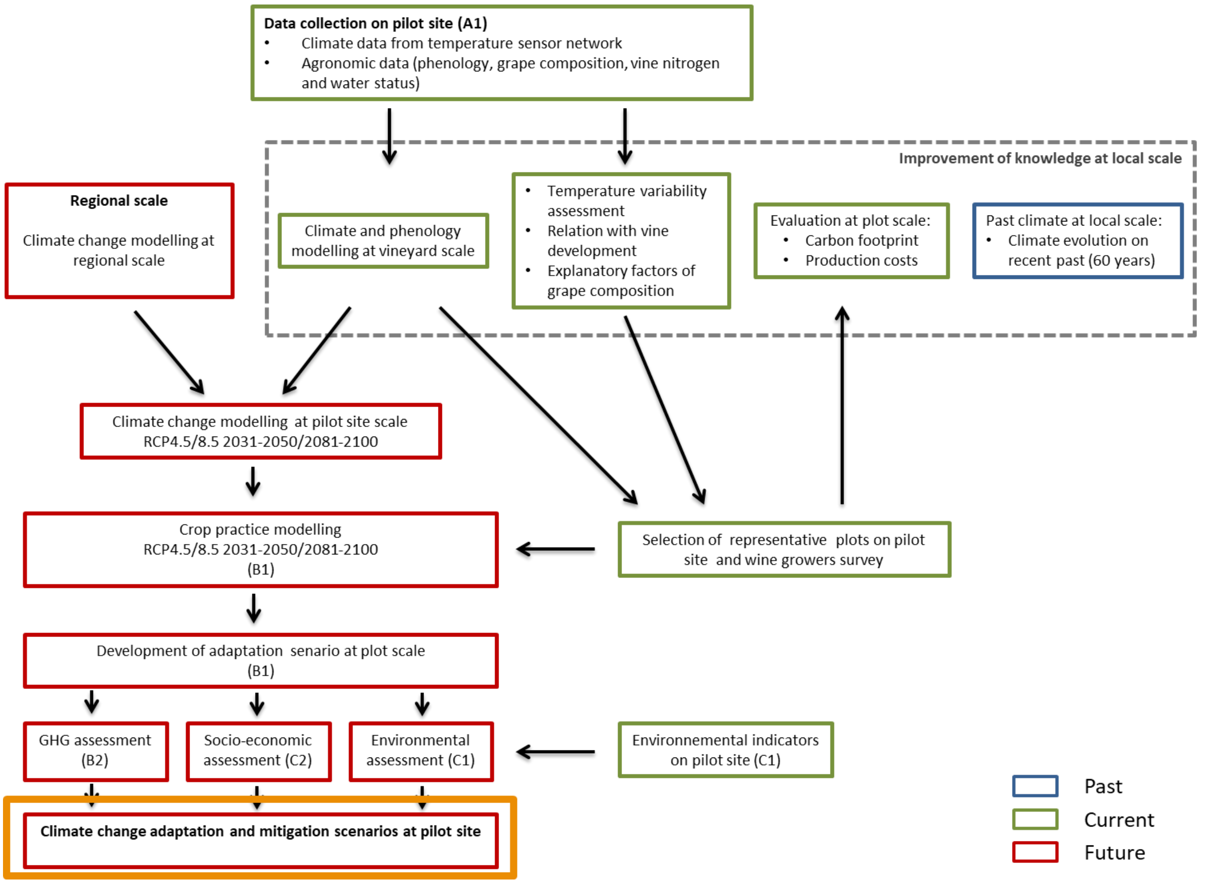
For the GHG emission level, plant protection and soil maintenance were identified as the most emitting (direct and indirect emissions) operations during the 2017 campaign. The variation in GHG emissions between operations is mainly caused by the engine power of vineyard tools and the frequency of interventions.

The SEVE model produced adaptation scenarios, which differed from current practice due to the number of pesticide applications: they remain stable or increase slightly for both periods. These increases can have a significant environmental impact, both on carbon footprint and water quality and biodiversity.

Regarding the socio-economic impact of climate change on viticultural operations, the most expensive operations are canopy management and winter pruning (both average of 1150€

per ha), due to the working time and the number of vineyard workers involved. However, the future increase in fungicide treatments could have an impact on production costs.

PART 5: OVERALL CONCLUSIONS



The overall results obtained on the Plumpton pilot site during the LIFE-ADVICLIM project are represented on the following graphics, which illustrate the results according to the different periods and scenarios, and show the tools developed to communicate and disseminate information for the stakeholders in wine production.

Past climate / regional scale

1951-1990 / 1991-2010

Tmean growing season : **+ 0,8°C**

Huglin Index : **+ 175 degree-days**

Current / pilot site scale

Climate

High temperature variability :

- Daily amplitude : **1.8°C** for minimum T°C (until 10°C) / **1.6°C** for maximum T°C
- Variability of Huglin index : **274 degree-days**

Strong effect of environmental factors on temperature distribution

- Tn and Tx : with **elevation** and **slope with southern exposure**
- Canopy WI : with **elevation** and **slope with southern exposure**

Vine development

Intra-annual variability of phenology and maturity (Pinot Meunier)

Budbreak	Flowering	Veraison
 3 days	 5 days	 3 days

Grape varieties :

Pinot Meunier / Acolon / Bacchus / Dornfelder / Ortega / Pinot Blanc / Pinot Noir / Regner / Riesling

Current / plot scale

GHG emissions

1800 kg eq CO_2/ha/year

Most emitted practices during one campaign :

Pest and disease management

Soil maintenance

Major factors of variation

Engine power

Frequency of interventions

Socio-economic indicators

Cost

4100 €

Most expensive practices during one campaign

Canopy management

Winter pruning

1150 euros/ha

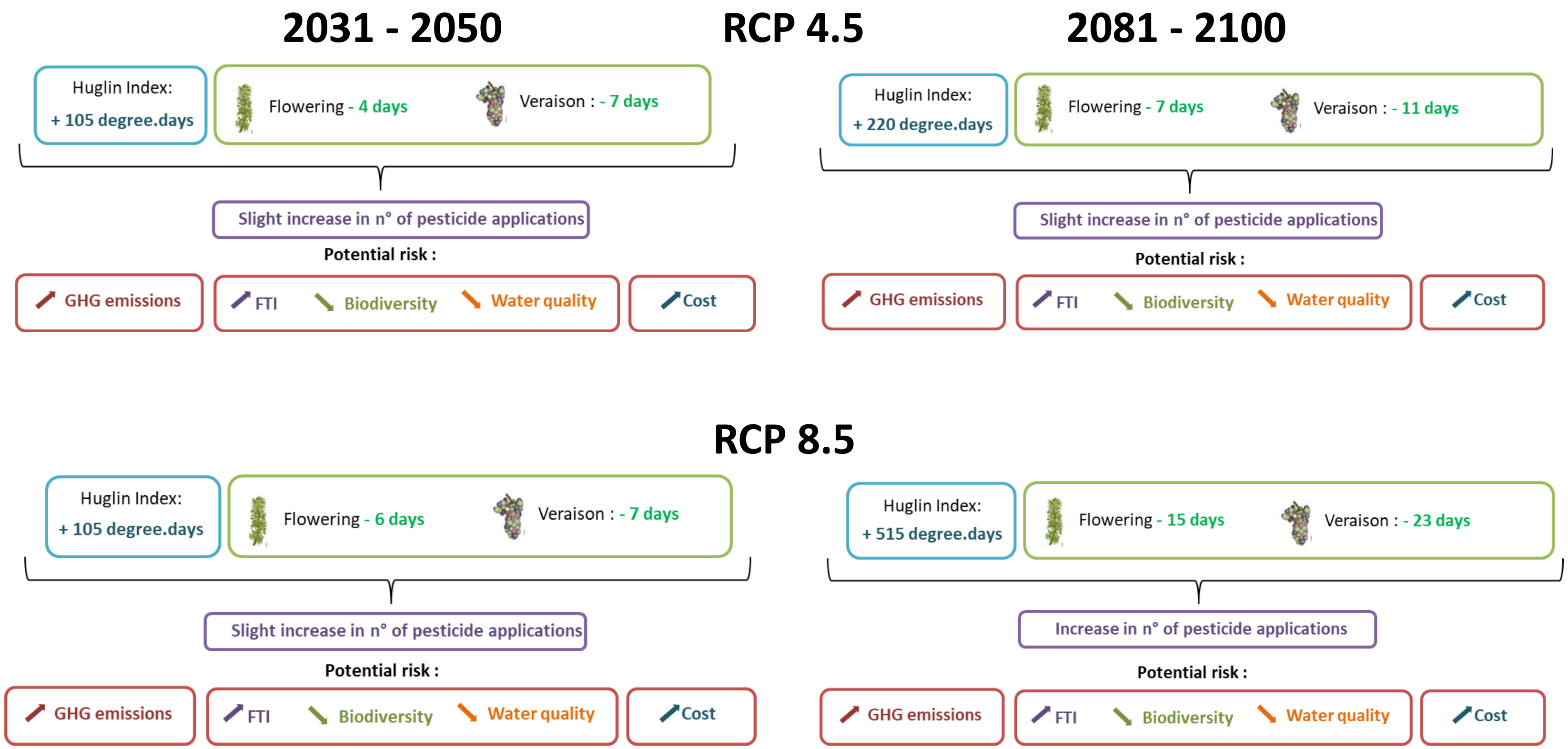
Major factors of variation

Number of practices

Working time

Number of workers

–Future / Pilot site and plot scale



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