LIFE-ADVICLIM PROJECT:
SAINT-EMILION/POMEROL 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 will 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 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, which can induce increased water deficit. Vine development and grape composition are strongly related to climate, so climate modification is a major challenge for wine production.

In this context, 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 Saint-Emilion/Pomerol pilot site for the B3 action, which aims to synthesize all the Life-ADVICLIM results.

General presentation of Saint-Emilion/Pomerol pilot site

The Saint-Emilion, Pomerol and their satellites appellations are located in the north eastern part of the Bordeaux area, on the right bank of the Dordogne, close to the city of Libourne at 40 km of Bordeaux. This area principally produces red wine, including some of Bordeaux' most prestigious estates, such as Châteaux Cheval-Blanc, Pétrus and Ausone. Most estates are small (around six ha) and many are still family owned. Saint-Emilion became famous at the end of the nineteenth century (much later than the Médoc and Sauternes regions), when Merlot became a major variety in Bordeaux. The reputation of Pomerol was established only in the twentieth century with the help of influential *négociants*, who were established in the town of Libourne in the 1930s. Viticulture has developed as the main agricultural activity, and has shaped the exceptional landscape we know today, obtaining recognition as a UNESCO World Heritage Cultural Landscape in 1999.

The main varieties grown in the Saint-Emilion and Pomerol area are Merlot (approximately 75%), Cabernet franc (approximately 16%) and Cabernet-Sauvignon (approximately 8%) (Cocks et al., 2014). Most vineyards are planted at densities of between 5,000 and 6,000 vines per hectare. The vines are Guyot pruned and the training system is vertical shoot positioning. For vineyard floor management, a cover crop is widely used, particularly on hillside vineyards to prevent erosion. Soil tillage is also a common practice, and the use of herbicides is declining.

The vineyards of Saint-Emilion and Pomerol are located on geological sediments that were established during the Tertiary and Quaternary era.

This area is characterized by several large tertiary limestone plateaus at approximately 100 metres in altitude, shaped by the erosion of rivers that flow south (Isle) and North-West (Dordogne) of the study site. On the valley floors, gravelly and sandy soils have developed on quaternary alluvium (van Leeuwen et al., 1989).

The climate is oceanic and temperate, with a total mean annual rainfall of 785 mm, and a mean annual temperature of 13.7°C (Data: *Meteo France* Saint-Emilion, average 1994-2015). Rainfall is well distributed throughout the year, but slightly lower in the summer.

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

In order to characterize temperature variability over this pilot site and the link with grapevine development and berry composition, a network of 90 temperature sensors, 60 phenological observation plots and 90 plots for monitoring maturity, was set up.

Using this measurement and observation network, the study of the link between climate at a local scale and grapevine development becomes possible. The spatial distribution of temperature was analysed, and temperature maps at a local scale have been produced. The grapevine response to temperature variability has been studied, as well as the relationship between temperature, vine water and nitrogen status, and grape composition.

The climate and phenological models developed in this first step permitted the downscaling of climate change modelling to a local scale. This was then coupled with regional climate change models based on RCP (Representative Concentration Pathway) scenarios 4.5 and 8.5, and the effect on vine development assessed.

Fifteen plots, representing the diversity of this pilot site in terms of environmental, economic, social and technical characteristics, were selected. These plots enabled the characterisation of current cultural practices, and the modelling of their evolution according to different climate change scenarios. These results informed the development of adaptation scenarios at the vineyard scale, in order to support vinegrowers in their efforts to cope with climate change.

The sustainability of viticultural practices at the present time and in the future has been 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.

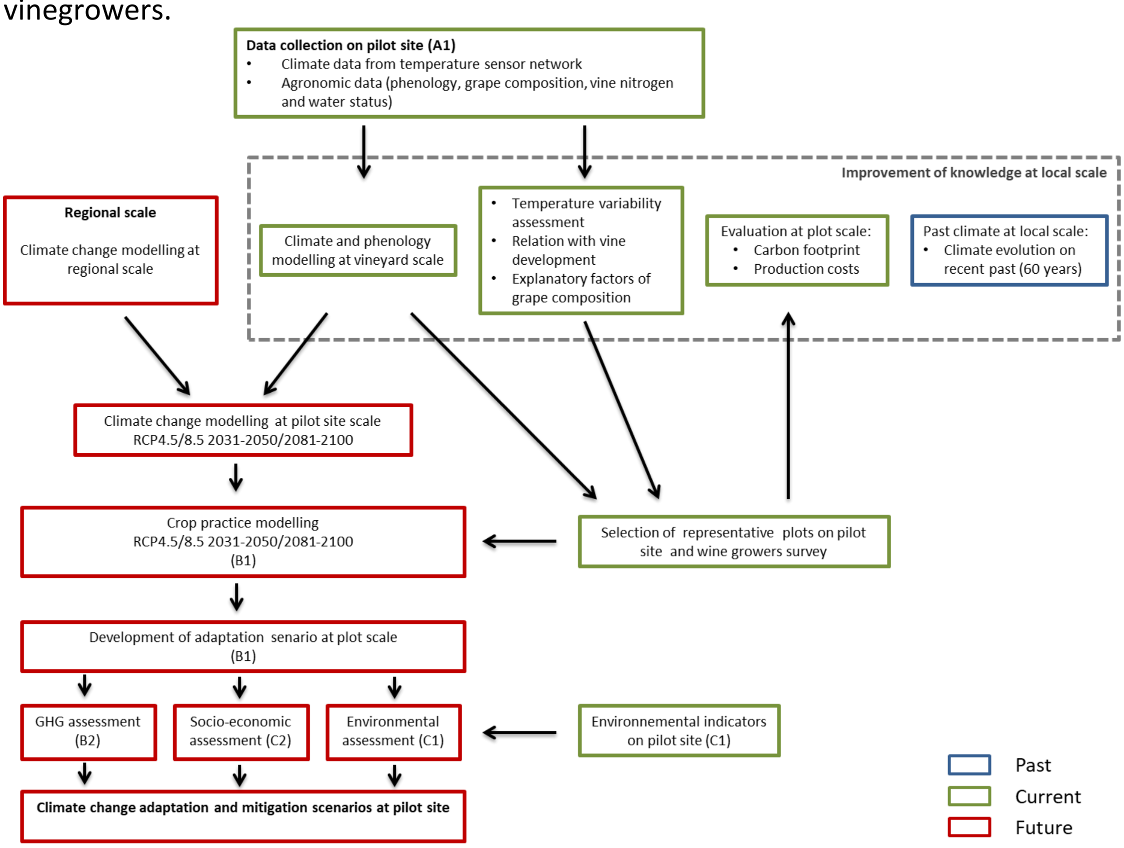
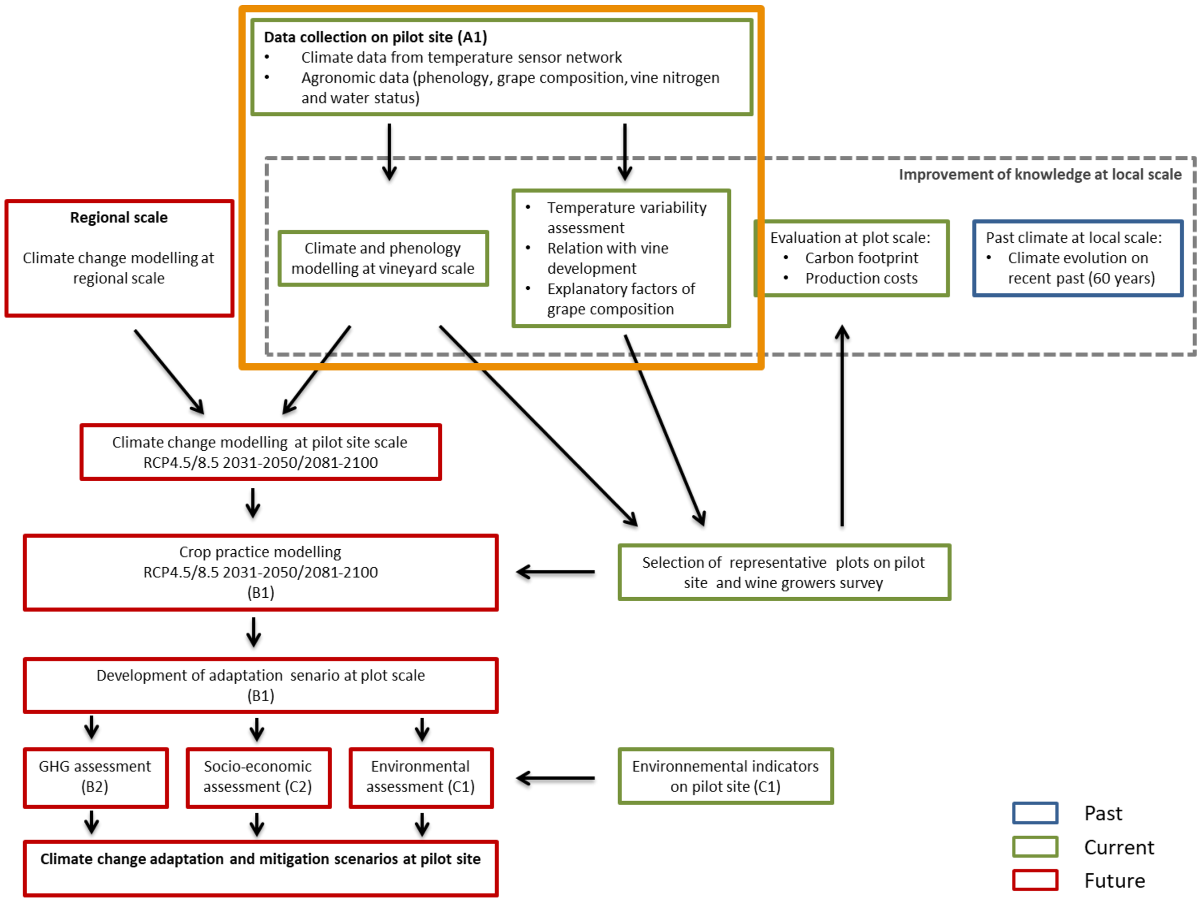


Figure 2: Synthesis of the B3 action

PART 1: FROM OBSERVATION TO MODELISATION AT THE VINEYARD SCALE: IMPROVING TERROIR ANALYSIS



In this ADVICLIM project action, an experimental protocol was implemented, designed to provide key inputs on temporal and spatial variability in viticulture. The Saint-Emilion/Pomerol pilot site was equipped with a network of temperature data loggers, where climatic and agronomic observations were carried out at the vineyard level. These field observations were integrated into a spatial analysis model, combined with local environmental features. The results generated could be linked to regional climate change projections, due to a better understanding of the local climate and of grapevine performance. Coupling bottom-up with top-down models allowed the construction of high-resolution outputs of current and future agro-climatic potentials.

1.1 Agro-climatic measurements implemented at the vineyard scale

1.1.1 Temperature network

In order to characterise the temperature variability over this vineyard area of 12,200 ha, a network of 90 temperature sensors was set up in 2012. This represents to a density of 1 sensor per 210 ha. At this local scale, it is important to take into account the topography (exposition, slope, and elevation), the latitude and longitude, but also local parametres, such as rivers, urban areas, and soil types, which can have an influence on the spatial distribution of temperature (Figure 3).

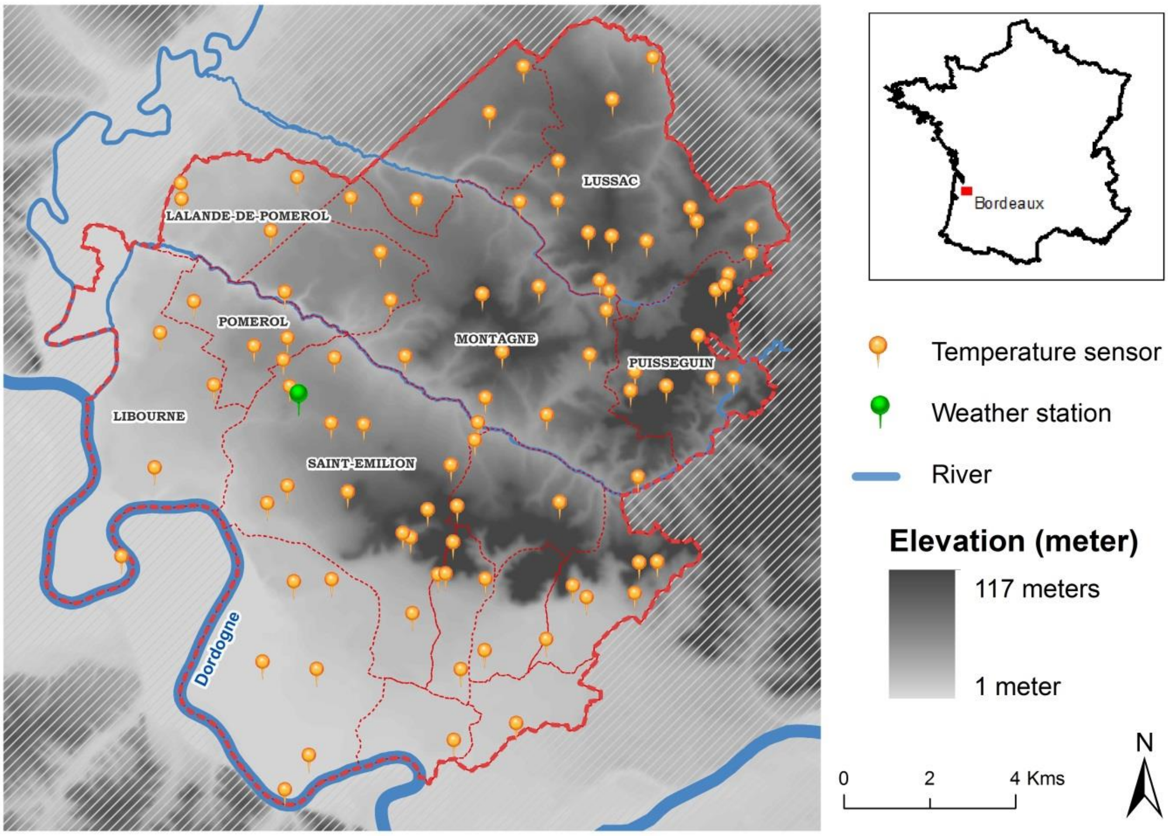


Figure 3: Localisation of temperature sensors projected on a Digital Elevation Model (IGN)

The temperature sensors used in this project are Tinytag Talk2 (Gemini Data Loggers, UK). These sensors were installed on vine posts within vineyard plots, recording both minimum and maximum hourly temperatures. In the frame of this European project, an automatic data recovery system has been developed using the *LoRa* technology. Four gateways were installed on this pilot site to retrieve the temperature data to an *Orbiwise* computer server, then on to *Ecoclimasol's* VIDAC platform (Figure 4).

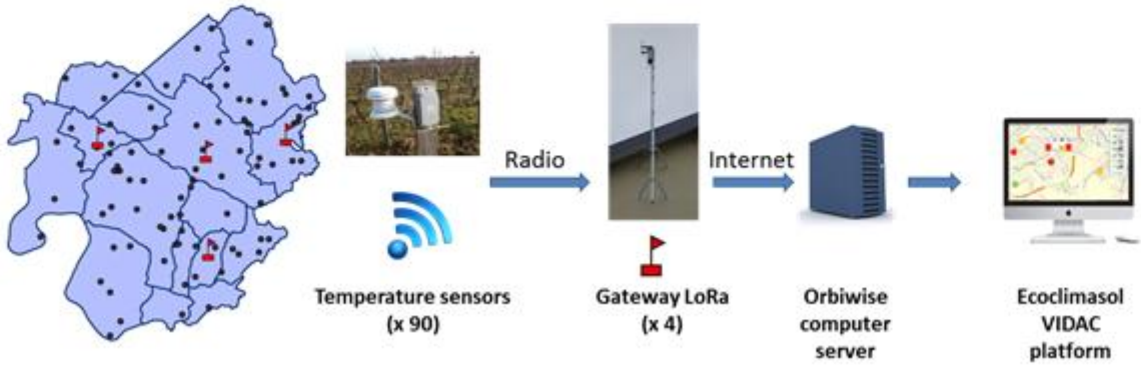


Figure 4: Automatic data recovery in the Saint-Emilion/Pomerol pilot site

1.1.2 Ecophysiological measurements

Ecophysiological measurements were carried out, to monitor grapevine development and berry composition, on blocks located near temperature sensors planted with the Merlot grapevine variety.

60 blocks were monitored for phenological stages (budbreak, flowering and veraison) with the specific day when 50 percent of vine organs reached stage "C" for budbreak, stage "I" for flowering and stage "M" for veraison being 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), malate (MAL) and pH levels were determined. In order to determine vine water status and vine nitrogen status, $\delta^{13}C$ and yeast available nitrogen (YAN) levels were measured (van Leeuwen 2009; van Leeuwen and Friant, 2011).

A more detailed assessment of berry maturity dynamics was carried out on 18 blocks. Every week, starting at the veraison stage, major grape metabolites were measured and, prior to harvest, the phenolic compounds (anthocyanin, polyphenol, seed maturity) were analysed.

1.2 Temperature analysis at the local scale

1.2.1 Climate evolution in the recent past

To measure the recent evolution of the climate in the Bordeaux wine growing area, the meteorological data of the weather station of Merignac (Météo-France data) have been used. A comparison between the periods 1951-1980 and 1981-2010 have been done (Table 1).

Table 1: Evolution of some climatic parameters and bioclimatic indices for the Bordeaux wine growing region, between 1951-1980 and 1981-2010 (Data from weather station of Mérignac, Méréo-France)

	From 1951 to 1980	From 1981 to 2010	Difference between both periods
Absolute Tmin (°C)	-15,2	-16,4	-1,2
Absolute Tmax (°C)	38,3	40,7	2,4
Annual mean temperature	12,5	13,8	1,3
AvGST (°C)	16,2	17,7	1,5
Winkler Index (degree-days)	1359	1666	307
Huglin Index (degree-days)	1795	2068	273
Annual precipitation (mm)	936	944	8
Number of days with Tmax>35°C	18	79	61
Number of days with Tmin < -3°C	13	8	-5

A positive evolution of 1.3°C for the annual average temperature and of 1.5°C for the average temperature of the growing season (AvGST; Jones, 2005) was measured. However, there is no significant evolution of the precipitation between these both periods. Concerning the bioclimatic index, an important evolution was recorded, with for example and increased of 273 degree-days for Huglin index (Huglin, 1978). The evolution switched the classification of the Huglin index from Cool class (IH-2) to Temperate class (IH-1) (Table 2).

Table 2: Classification of winegrowing climate from Huglin index (Huglin, 1978)

Très chaud	IH+3	3000 < IH
Chaud	IH+2	2400 < IH ≤ 3000
Tempéré chaud	IH+1	2100 < IH ≤ 2400
Tempéré	IH-1	1800 < IH ≤ 2100
Frais	IH-2	1500 < IH ≤ 1800
Très frais	IH-3	IH ≤ 1500

Another important point is the evolution of the number of days characterized by a daily maximum temperature superior to 35°C. During the period 1951-1980, 18 days superior to 35°C were recorded against 79 days for the period 1981-2010. Regarding the annual frost days characterized by a minimal temperature inferior at -3°C there is a reduction of 5 days between the both periods.

1.2.2 Daily temperature amplitude analysis

It is of particular interest to look at the daily amplitude of minimum and maximum temperatures over the study area (i.e. the difference between the highest and the lowest minimum respectively maximum temperature recorded over the study area on a particular day).

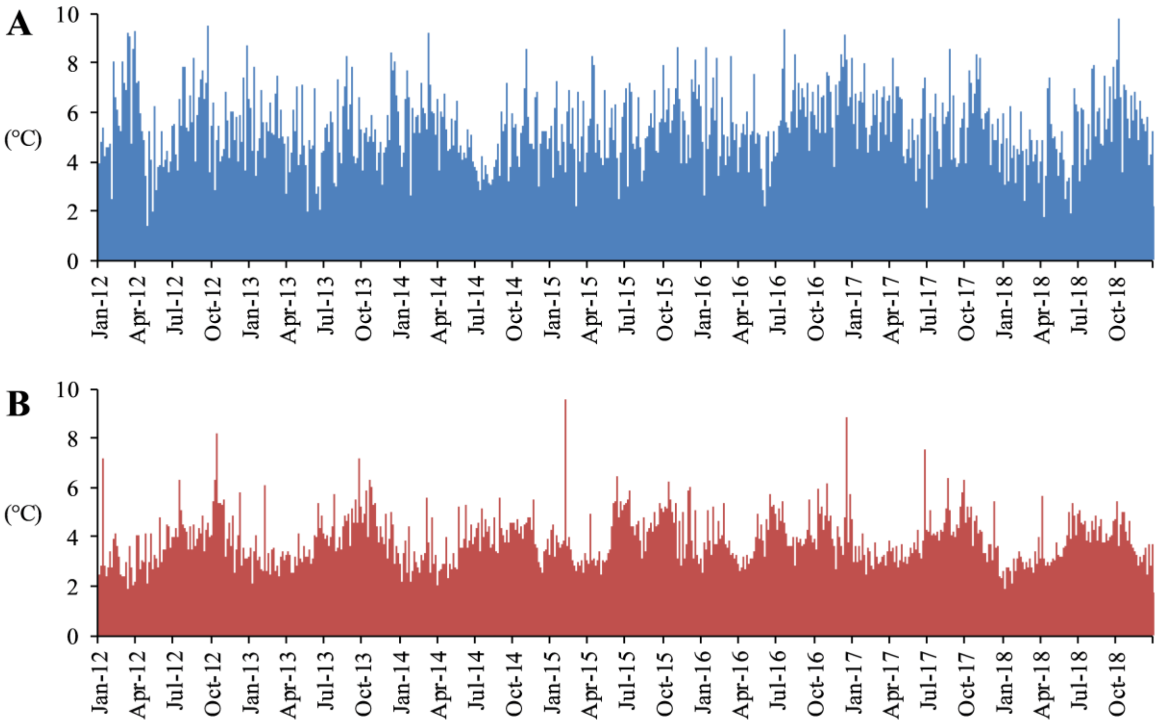


Figure 5: Daily thermal amplitude for minimum (A) and maximum (B) temperatures over the Saint-Emilion/Pomerol pilot site, from 2012 through 2018

Great spatial daily variability in temperature amplitude is shown, especially for minimum temperatures with an amplitude of up to 10°C on specific days with anticyclonic clear sky conditions. These particular days are characterized by a thermal inversion on minimum temperature, with warm air located at higher altitudes and cooler air in the valleys (Figure 5A).

The amplitude of maximum daily temperature was mostly around 3.2°C±0.9, while the amplitude of minimum daily temperature was about 3.9°C±1.7. The daily thermal variations on minimum temperatures are greater than those of maximum temperatures, but the latter presents more seasonal variations (Figure 5B).

1.2.3 Temperature variability of the vegetative season

Average daily mean, minimum and maximum temperatures were analyzed during the growing season, from April 1st to September 30th during 7 consecutive years (2012-2018) (Figure 6).

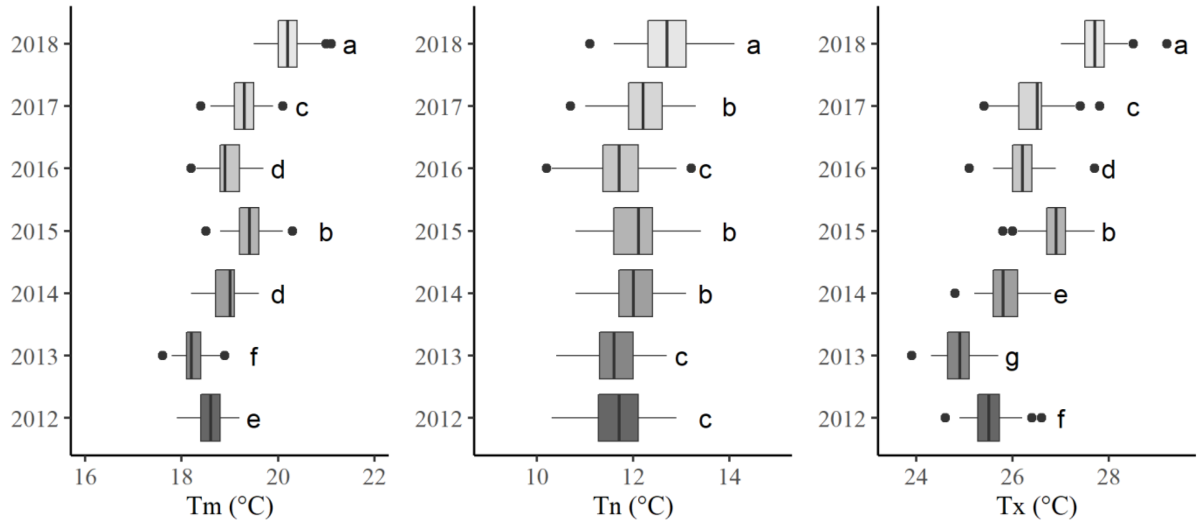


Figure 6: Boxplots on mean (Tm), minimum (Tmin) and maximum (Tmax) average daily temperatures over the growing season (from April 1st to September 30th) from 2012 through 2018. Different letters indicate significant differences between years (at P < 0.05).

The average mean temperature is around 19.1°C ±0.6 (with a mean amplitude of 1.5°C ±0.2) and shows a marked vintage effect: 2018 is the warmest and 2013 the coolest year.

The intra-annual spatial variability, which corresponds to the range of temperatures between the coldest and the warmest sensor, is greater for minimum temperatures (2.6°C ±0.3 in average over the 7 vintages) than for maximum temperatures (2.1°C ±0.3 in average).

The inter-annual (temporal) variability is greater on mean and maximum temperatures than on minimum temperatures. The multiple comparisons performed after the ANOVA show only 3 groups for the minimum temperatures in comparison to 6 and 7 groups for respectively the mean and the maximum temperature. Hence in this site, the vintage effect is mainly due to variations in maximum temperatures.

1.2.4 Bioclimatic Indices: Winkler Index

The Winkler 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 (Winkler, 1974). This index is based on the sum of temperatures above 10°C, from April 1st to October 31st (in the northern hemisphere). When these temperatures are measured inside the canopy, this index is referred to as the Canopy Winkler Index (de Rességuier, 2018).

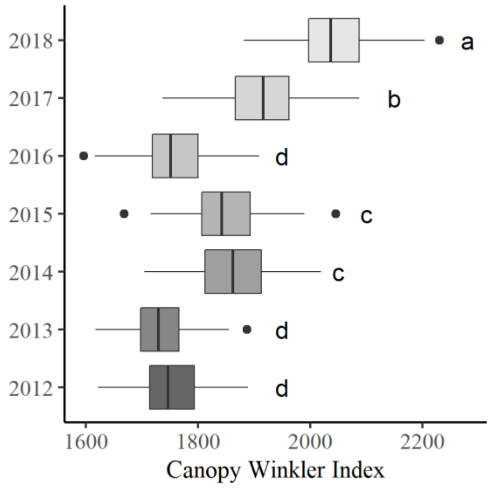


Figure 7: Boxplots of Canopy Winkler Index from 2012 through 2018. Different letters indicate significant differences between years (at P < 0.05).

An important vintage effect was highlighted (2018 was the warmest and 2013 the coldest vintage, with a CWI of respectively 2041 degree-days ±72.6 and 1735 degree-days ±55.4). The spatial amplitude was also substantial, with an average of 320 degree-days ±41.7 over the seven years studied (Figure 7). Given this wide temperature range, and without taking into account other parameters which can also potentially influence grape composition, maturity could be delayed by approximately 30 days in the latest ripening parcels, compared to early ripening parcels.

1.2.5 Climate modelling adapted to the vineyard scale

1.2.5.1 Fine scale modelling

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

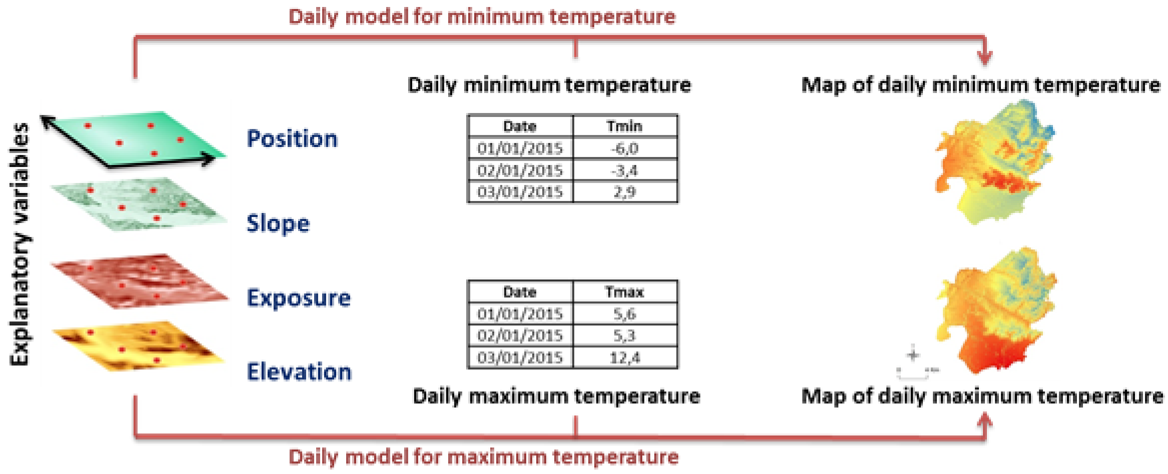


Figure 8: Schematic synthesis of the production of daily temperature maps

Using the data extracted from the data loggers, the model allows to spatialize the relationships between the temperature distribution and the local environment and to map the daily maximum and minimum temperature over the studied years (2012-2017) (Figure 8). Based on these daily maps, the average minimum and maximum temperatures and the bioclimatic indices mentioned above were mapped in order to visualise their spatial variability.

1.2.5.2 Climate modelling results

The models (Tmin, Tmax, WI, 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.

1.2.5.2.1 Spatial distribution of minimum and maximum temperatures during the vegetative season

The analysis of the average minimum (Tmin) and maximum (Tmax) temperature maps over the studied years revealed a high spatial variability (Figure 9). For Tmin, the sectors with the highest altitudes (the limestone plateaus of Saint-Émilion, Montagne, Puisseguin and Lussac), as well as those on southerly-exposed slopes, correspond to the areas with the highest minimum temperatures. Conversely, the lowest sectors (valleys and the Dordogne plain) are associated with the lowest temperatures, which may be due to the effect of thermal inversion situations and topography (Beltrando and Chémery, 1995). There is also a marked difference between the west and east sectors of the study area. The minimum temperatures in the western part (Libourne, Pomerol, and Lalande-de-Pomerol) are slightly above average, while the altitudes are relatively low and the topography is pretty flat.

For the spatial distribution of maximum temperatures (Figure 9), the opposite spatial pattern is observed: the warmest temperatures are recorded at low altitudes and cool temperatures at high altitudes. Some high maximum temperatures are also recorded in the western part of the area (appellations Pomerol, Lalande de Pomerol and the commune of Libourne).

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.

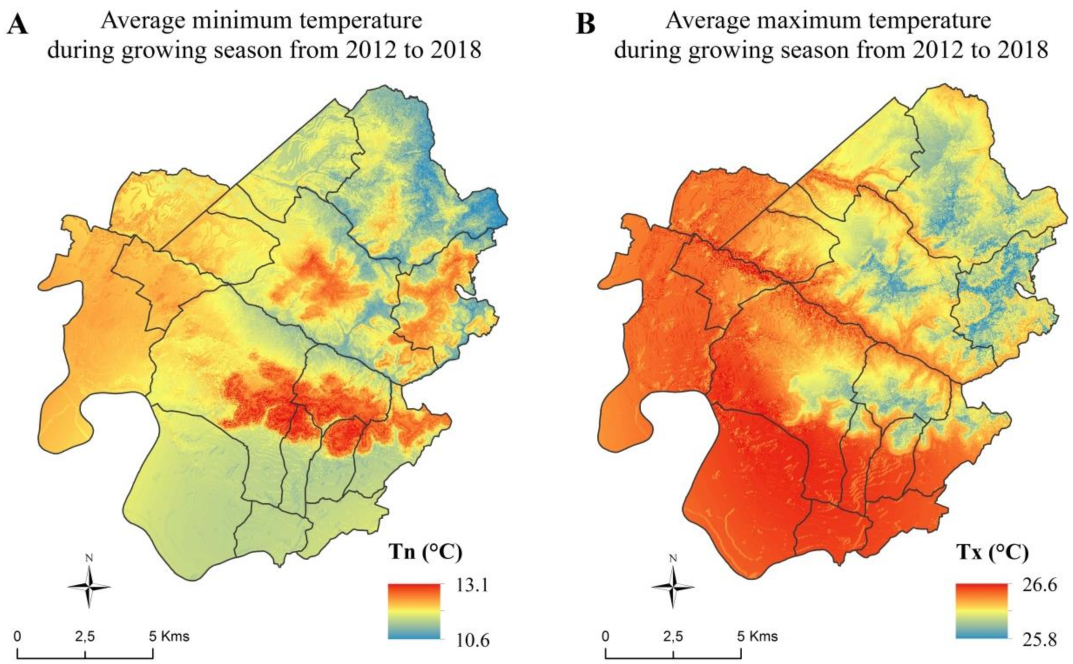


Figure 9: Spatial distribution of average minimum (A) and maximum (B) temperatures during the growing season (2012-2017)

1.2.5.2.2 Spatial distribution of Canopy Winkler and Huglin Indices

Canopy Winkler Index

The spatial distribution of the Winkler Index is similar to that of average minimum temperatures: plateaus and slopes have the highest values, and areas with the lowest altitudes have the lowest values. However, the Winkler index is strongly correlated with average temperatures during the growing season (Jones, 2005). The distribution of average temperatures is therefore highly dependent on minimum temperatures. These results can be explained by the fact that, at the local scale, the spatial variability of maximum temperatures is lower compared to minimum temperatures (Carrega, 2003).

Canopy Huglin Index

The Huglin index, as a result of its construction, gives a greater weight to maximum temperatures. The south-facing slopes of the Saint-Emilion hillside and the Libourne/Pomerol/Lalande de Pomerol sectors are those with the highest index values. Low altitude areas generally have fairly high values, while the plateaus and the north-eastern part of the study site are the areas with the lowest index values (Figure 10).

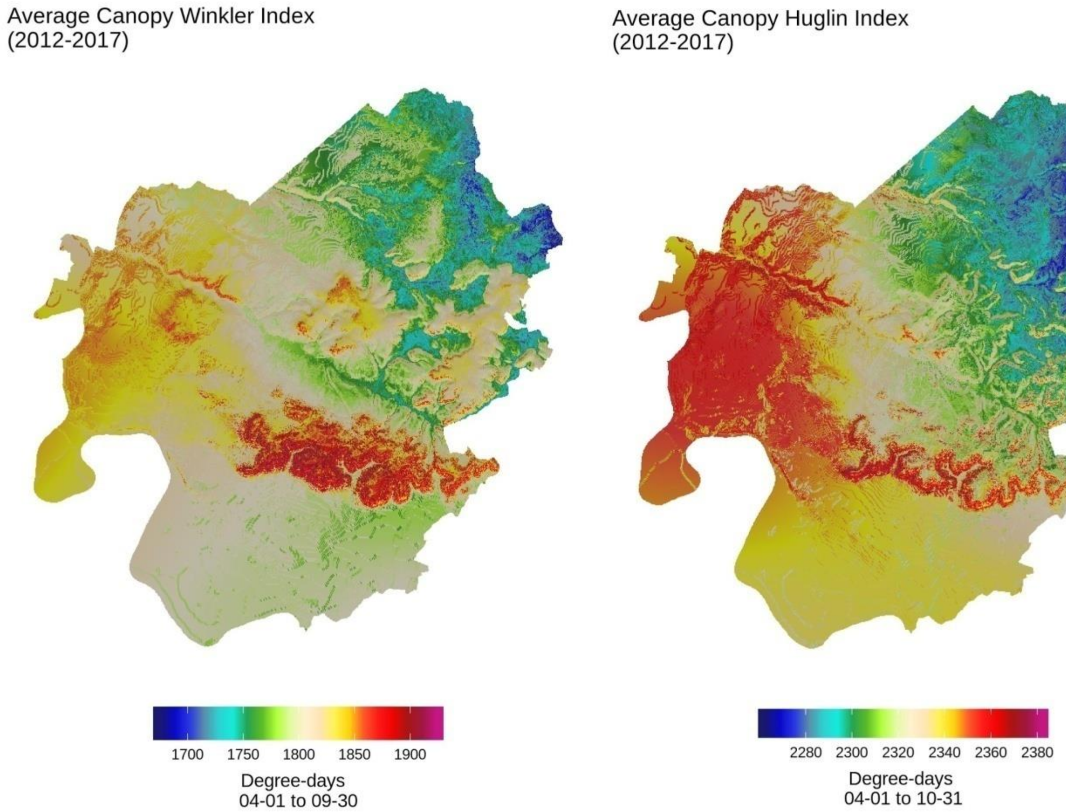


Figure 10: Spatial distribution of the average Canopy Winkler and Canopy Huglin Indeces (2012-2017)

1.2.6 Study of environmental factors that explain temperature distribution

A statistical analysis was implemented to select the geomorphological co-variables which drive temperature distribution (Table 3).

The mains factors impacting minimum temperature over vegetative season are elevation, longitude, slope and latitude. Tmin increased with elevation and the percentage of slope, and decreased from West to East and from South to North part of this area. Significant, but less important effects have been found for exposure variables. The effect of elevation was, however, contingent on slope, and exposure parameters. For example, the negative coefficient parameter estimates for the interaction between elevation and slope indicated that the increase of minimum temperature with elevation is stronger in very steep vineyards than in parcels with low declivity.

Regarding maximum temperatures, the main effect is elevation. Tmax decreased with elevation and increased with percentage of slope. The effect of elevation was, however, contingent on slope on South/North exposure and on East/West exposure. Regarding the interaction between elevation and West/East exposure, the positif coefficient suggested that the effect of elevation on maximum temperatures was lower in West facing parcels.

Canopy Winkler index increased with elevation, slope and decreased with South/North exposure, longitude and latitude. The effect of elevation was concomitant with slope. The negative coefficient parameter estimates for the interaction showed that the increase of

Canopy Winkler Index with elevation was higher in steep vineyards than for parcels with low declivity.

Table 3: Summary of Linear Mixed-Models testing the effect of elevation, slope, exposure, latitude and longitude on maximum temperature, minimum temperature and Canopy Winkler Index. P-values are indicated within brackets and significant effects are shown in bold.

	Maximum temperature			Minimum temperature			Canopy Winkler Index		
	Estimate	Std.Error	χ^2-value	Estimate	Std.Error	χ^2-value	Estimate	Std.Error	χ^2-value
Elevation	-6,9E-03	9,0E-04	**126.0 (<0.001)**	2,3E-02	1,0E-03	**681.9 (<0.001)**	1,85E+00	1,37E-01	**174.6 (<0.001)**
Slope	6,7E-02	1,6E-02	**16.6 (<0.001)**	1,1E-01	1,8E-02	**108.0 (<0.001)**	2,03E+01	2,38E+00	**133.0 (<0.001)**
South/North exposure	2,0E-01	5,1E-02	0.1 (0.7)	-2,5E-01	5,8E-02	**6.4 (0.01)**	-6,78E+00	3,07E+00	**4.9 (0.03)**
West/East exposure	-4,1E-01	6,8E-02	7.3 (0.007)	2,9E-01	7,6E-02	**14.8 (<0.001)**	3,28E+00	3,69E+00	0.8 (0.4)
Longitude	-6,2E-07	5,0E-06	0.02 (0.9)	-1,3E-04	5,0E-06	**574.1 (<0.001)**	-1,00E-02	1,00E-03	**377.3 (<0.001)**
Latitude	-1,0E-05	4,0E-06	1.9 (0.2)	-4,0E-05	5,0E-06	**68.0 (<0.001)**	-4,85E-03	1,00E-03	**62.7 (<0.001)**
Elevation * Slope	-1,0E-03	3,2E-04	**10.3 (0.001)**	-1,2E-03	3,6E-04	**10.3 (0.001)**	-2,60E-01	4,90E-02	**28.8 (<0.001)**
Elevation * South/North exposure	-3,5E-03	8,4E-04	**17.2 (<0.001)**	3,5E-03	9,5E-04	**13.2 (<0.001)**	/	/	/
Elevation * West/East exposure	7,0E-03	1,3E-03	**29.7 (<0.001)**	-3,7E-03	1,4E-03	**6.6 (0.01)**	/	/	/

1.3 Vine response to spatial temperature variability

1.3.1 Phenological observations

The dates of phenological events were monitored on 60 plots of Merlot from 2012 to 2016 (2017 is not included because of frost damage).

Phenology monitoring revealed the importance of the vintage effect: the warmer climatic conditions of 2018 and 2015 advanced the timing of phenological stages compared to the cool year 2013 (Figure 11). The duration of phenophases between the subsequent phenological stages was variable from year to year. Some vintages, like 2016, can have an early budbreak due to high temperatures during the beginning of the year followed by a late flowering and véraison, because of relatively lower temperatures later in the growing season.

Another point that was highlighted in this study is the intra-annual variability. An average window of about 19 days ±7.7 was recorded for budbreak, 9 days ±2.9 for flowering, 13 days ±4.5 for véraison and 25 days ±11.3 for theoretical maturity (200g/L of sugar content). The standard deviation shows that there is more variation between years for budbreak and maturity, which is certainly due to climatic conditions during these phenophases that can affect their duration. For example, the maturity of the 2013 vintage was impacted by the poor ripening conditions that led to a delay of maturity.

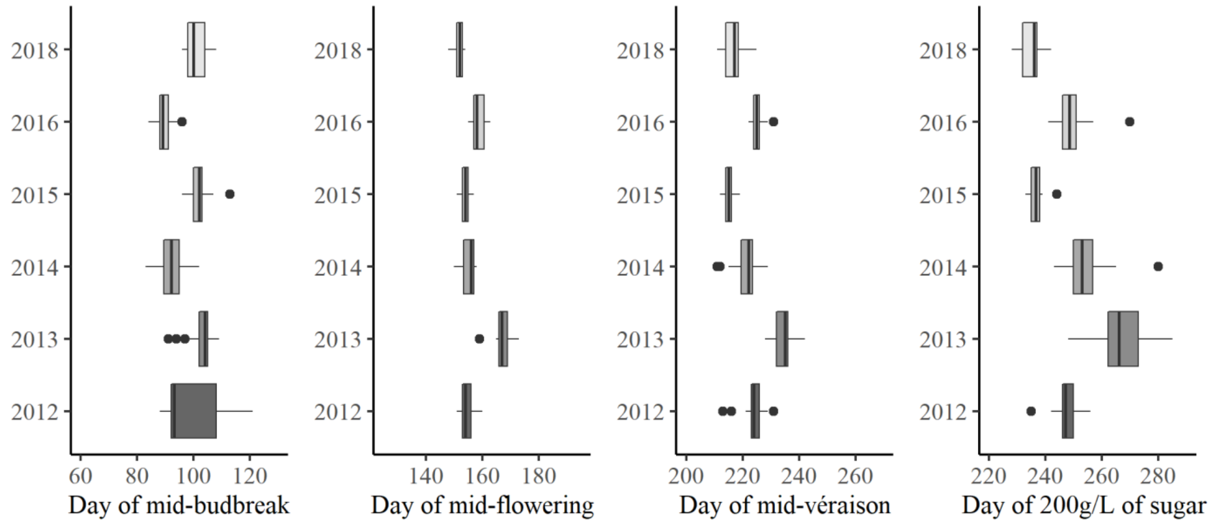


Figure 11: Boxplots of observed phenological stages from 2012 through 2018

1.3.2 Phenology modelling adapted to the vineyard scale

1.3.2.1 Phenological models developed on the pilot site scale

Using daily temperatures, phenological observations and the Phenology Modelling Platform (PMP) developed by the CNRS, four models have been successfully developed to characterise the timing of budbreak, flowering, veraison and sugar maturity in this area.

These phenological models, combined with climatic models developed in this project (Le Roux et al. 2017) allow the creation of maps predicting the different phenological stages in the Saint-Emilion/Pomerol pilot site (Figure 12).

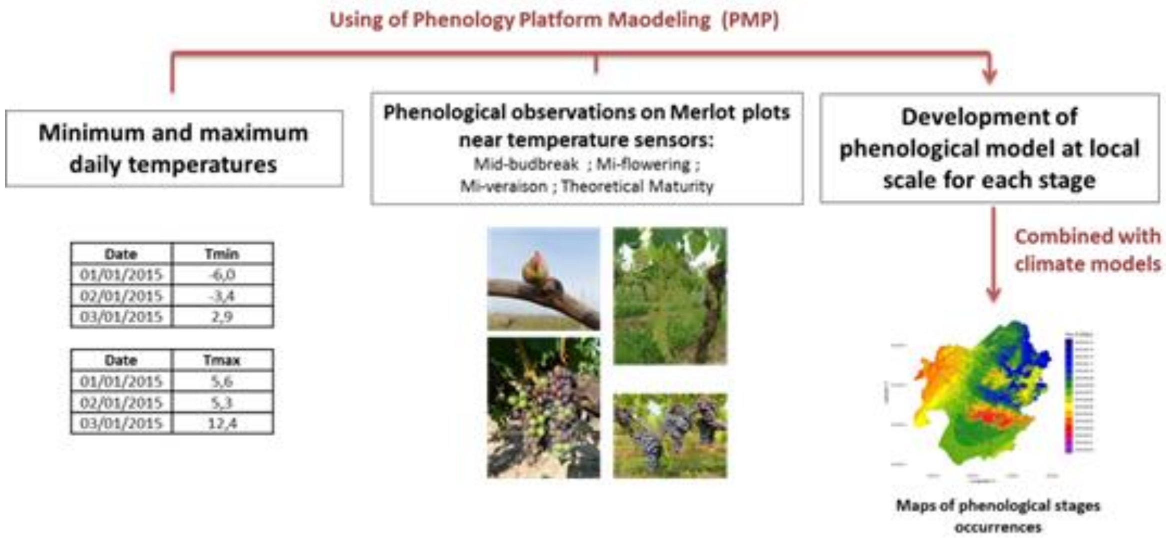


Figure 12: From observations to phenological maps at local scale

1.3.2.2 Maps of the phenological stages

Figure 13 represents the spatial distribution of the timing of four key phenological stages, averaged over the period 2012-16. Although the modelling moderates the amplitude across the area (especially for budbreak and maturity), the largest amplitude is found for the maturity stage. The spatial structure of the other phenological stages is more or less constant. The grapevines on the limestone plateaus, the south-facing slopes and the western part of the area are the earliest to develop. The vines in the north east and the valley bottoms show delayed phenology.

The most interesting map for the vinegrower is that displaying the date at which the berries achieved a sugar level of 200 g/l, as this will enable them to better adapt plant material (grape variety, rootstock and clone), viticultural practices and harvest dates to different environmental conditions. For example, Merlot is more adapted to the north-eastern part of this area and Cabernet franc and Cabernet-Sauvignon, which are later ripening varieties, will give better results in term of maturity, complexity and aromas in the western part and on the early ripening limestone plateaus.

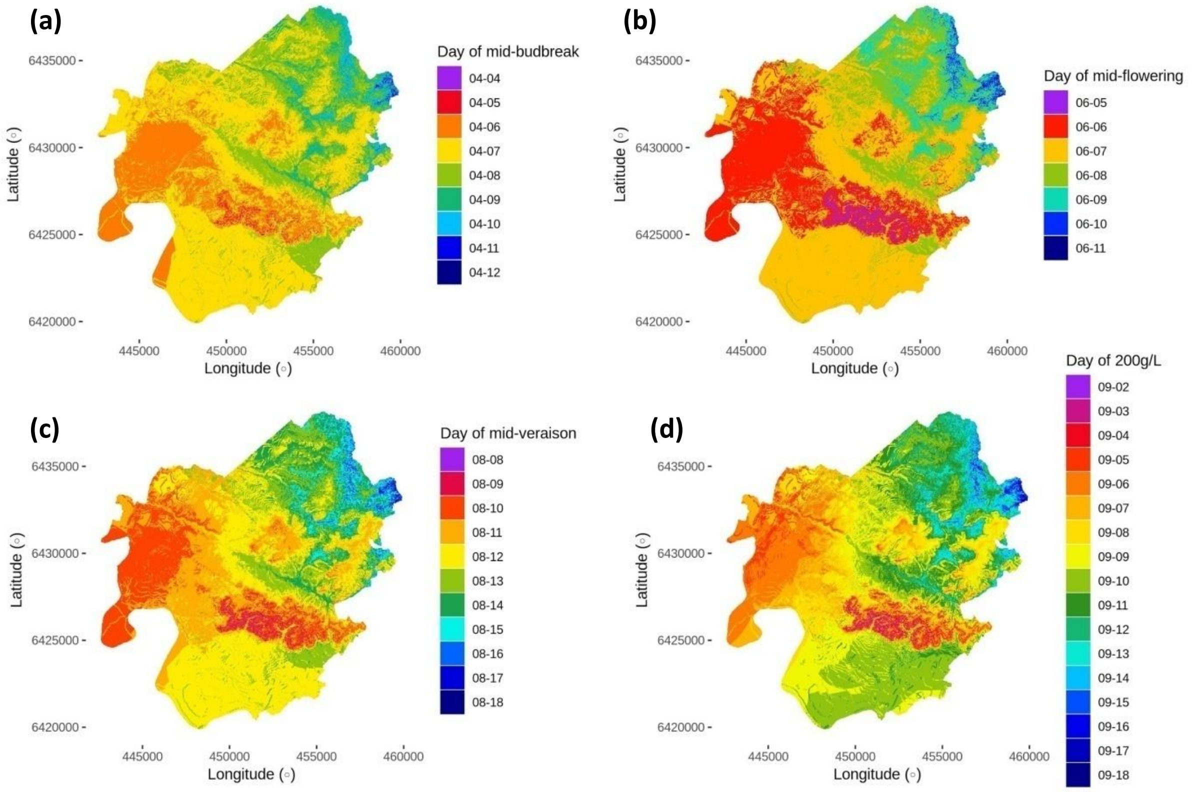


Figure 13: Maps of the average modelled occurrences of the four phenological stages (2012-2016).

a = mid bud-break, b = flowering, c = mid-veraison, d = day of 200g/L of sugar content

1.4 Relation between temperature, vine water and nitrogen status, and grape composition

Investigation of the relations between temperature, vine water status, vine nitrogen status, berry weight and grape compositions, were carried out by means of appropriate statistics. Regarding maturity index Sugar/TA, a strong effect of Tmin, Tmax and water deficit (as assessed by $\delta^{13}C$) is shown. Sugar/TA increases with the increase of these parameters. There is also a small effect of berry weight and YAN, maturity index decreases with theses parameters (Figure 14).

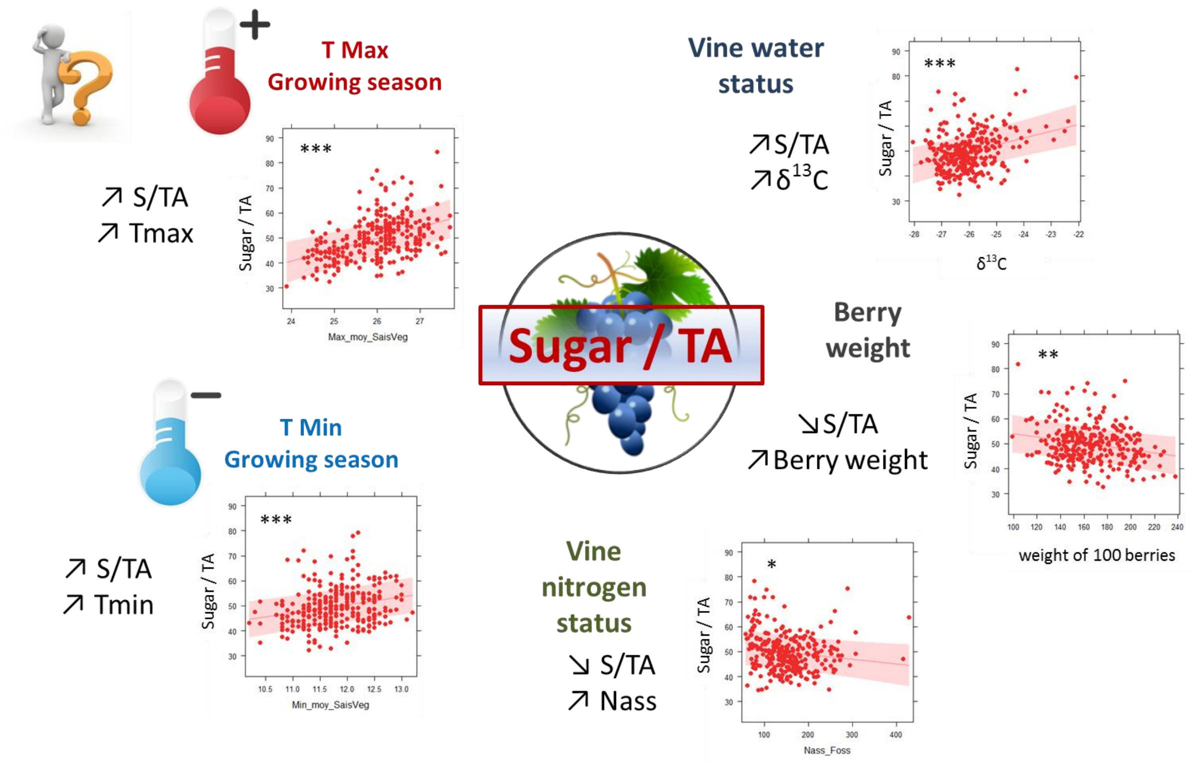


Figure 14: Relations between temperatures, vine water and nitrogen status and grape composition during growing season

Conclusion part 1

Figure 15 is a schematic synthesis of the first part of this report, which investigates the terroir of the Saint-Emilion/Pomerol pilot site.

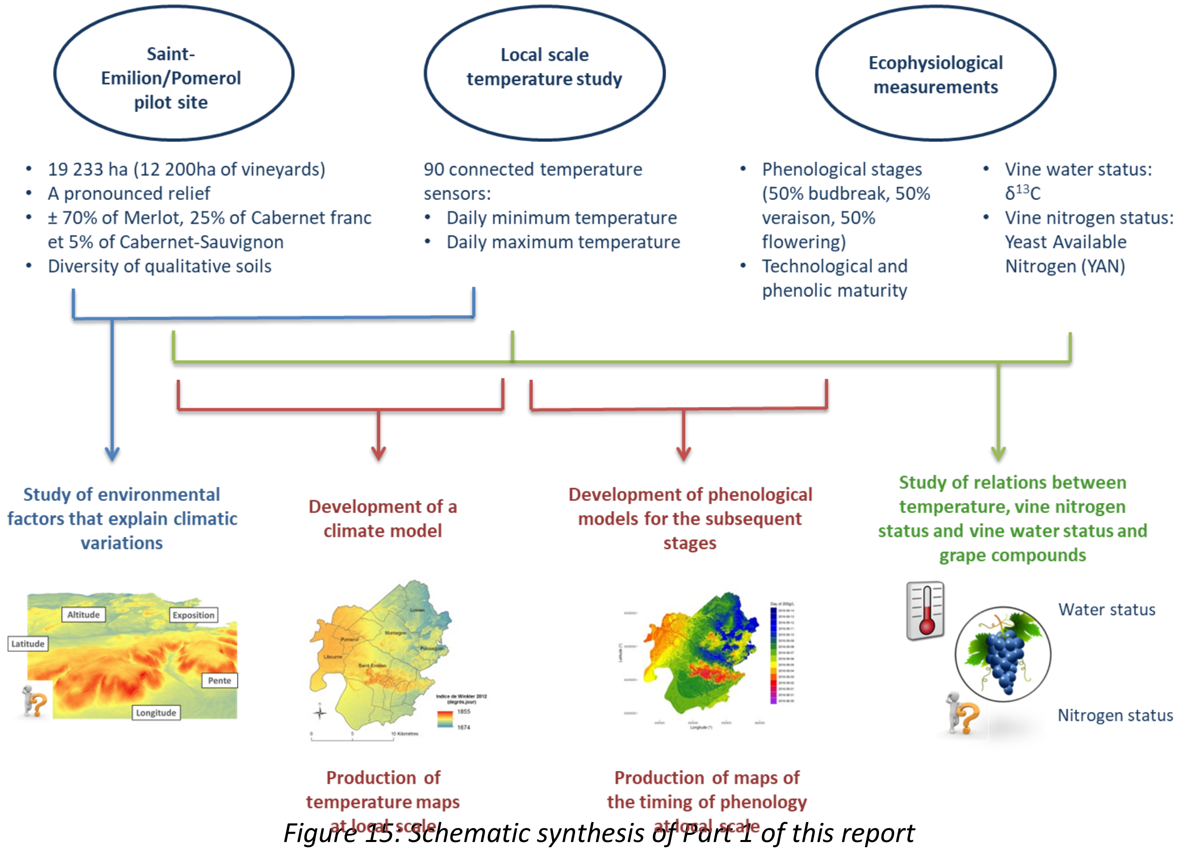
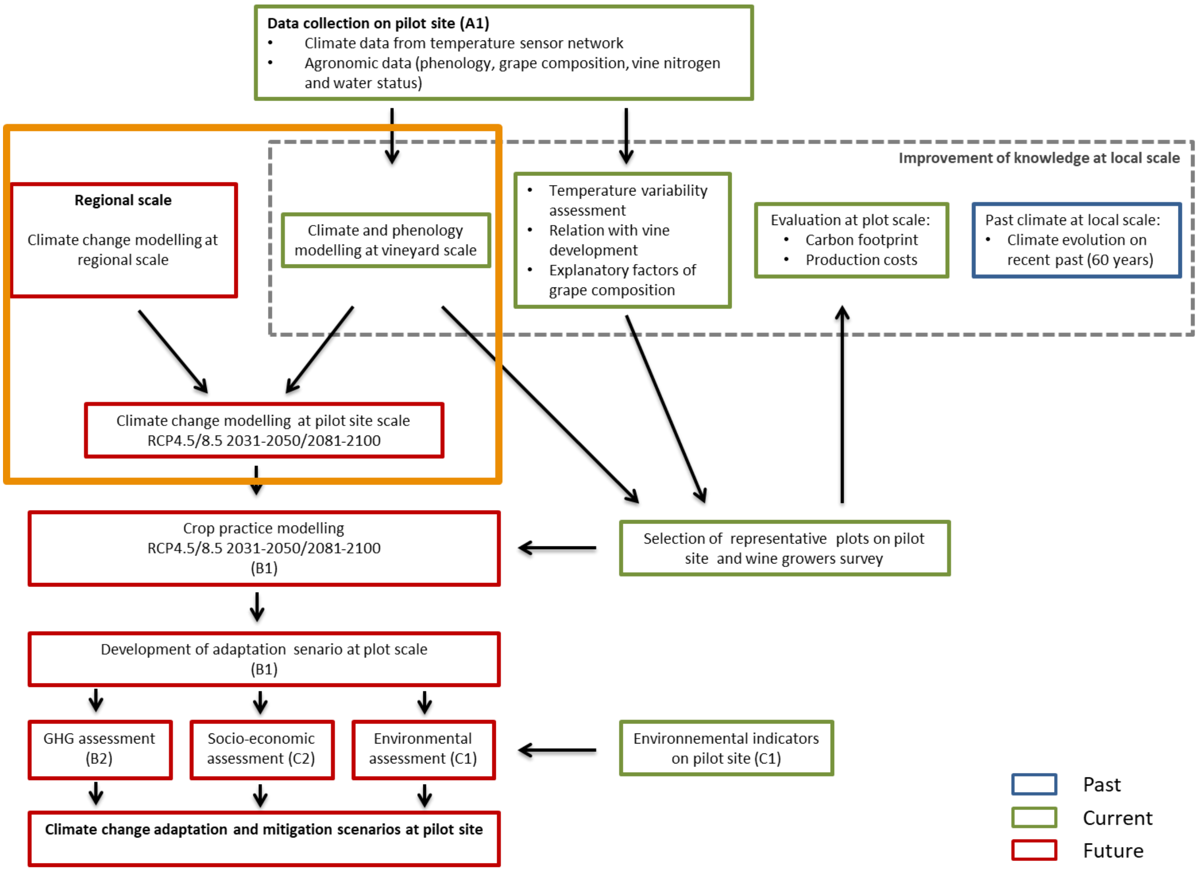


Figure 15: Schematic synthesis of Part 1 of this report

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 territory 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 in a changing climate. The models generated from this part of the report will be used to generate maps of climate change at scale vineyard.

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, production of temperature and phenological maps at vineyard scale 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 16).

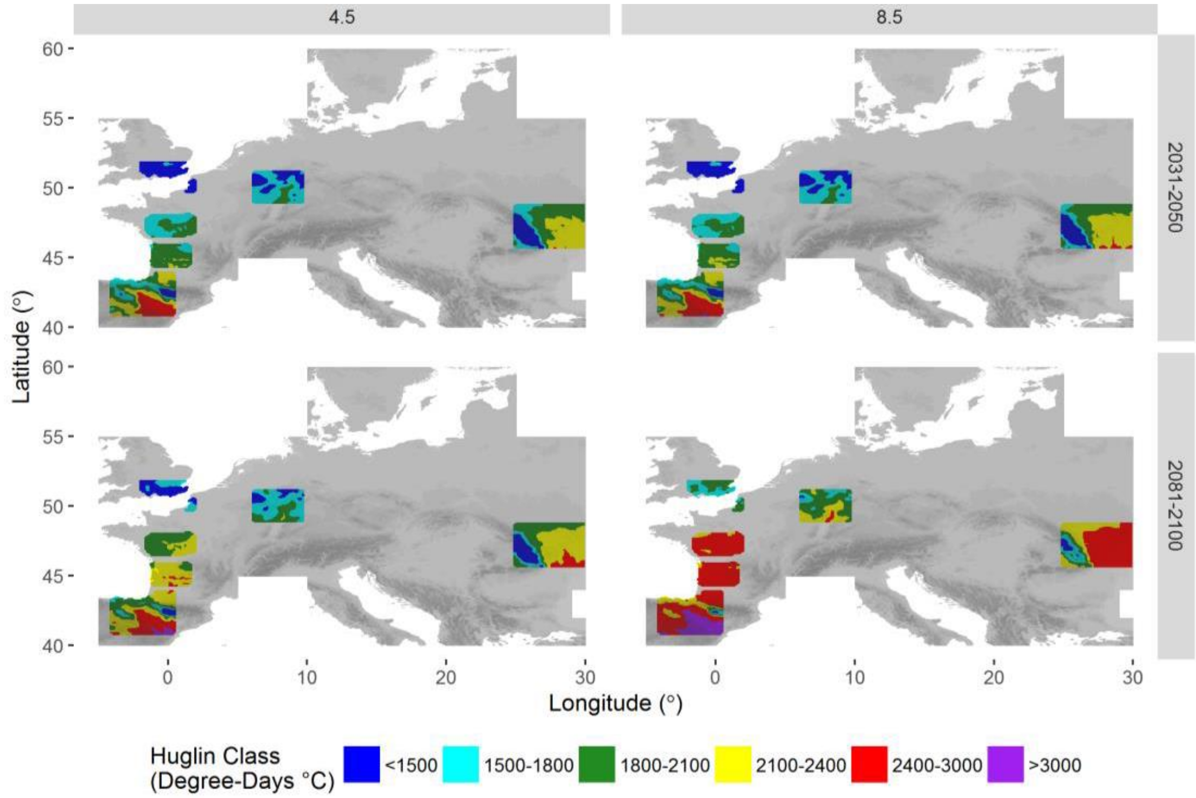


Figure 16: Expected changes in the Huglin Index for the period 2031 to 2050 and 2081 to 2100 according to the climate scenarios of RCP 4.5 and RCP 8.5. (Data source: EURO-CORDEX, R. Vautard).

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, it was then possible to calculate the bioclimatic indices investigated above, and map them at the scale of the pilot site in the medium and long term. Figure 17 represents the evolution of the Huglin index, comparing the historical period 1986-2005 in the Saint-Emilion/Pomerol pilot site to future periods and scenarios (Le Roux et al., 2018).

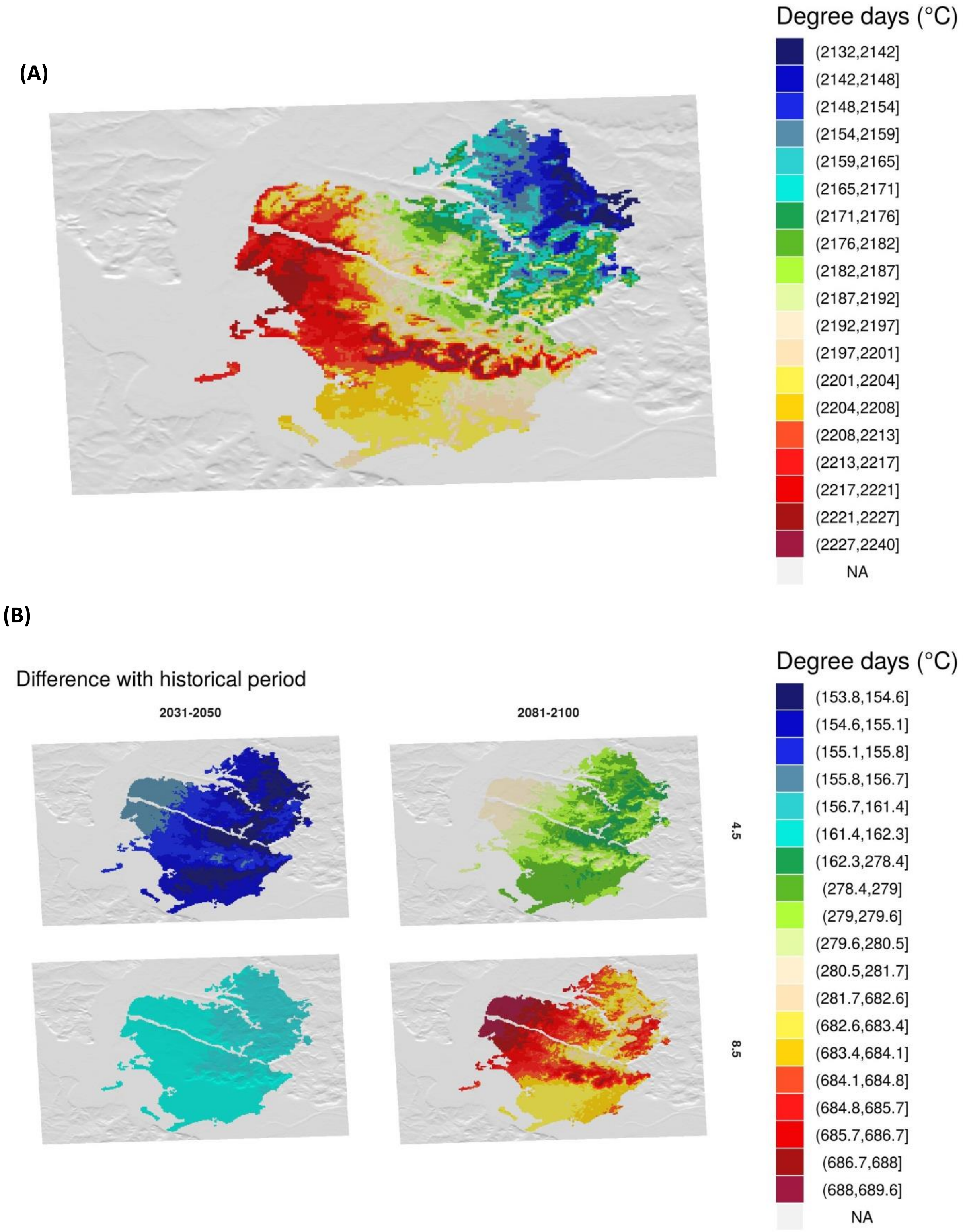


Figure 17: Maps of the Huglin Index over the Saint-Emilion/Pomerol pilot site for the period 1986 to 2005 (A) and expected changes in the Huglin Index (B) for the period 2031 to 2050 and 2081 to 2100 according to the climate scenarios RCP 4.5 and RCP 8.5.

These results indicate that there is no difference between the spatial distribution of the Huglin index in past or future whichever scenario is deployed. The difference is constant, about 110 degree-days, and the warmest areas will remain the warmest, and the same is true for the coldest areas (Table 4).

The results (Table 4) also demonstrate an increase in the growing degree-days over the investigated periods. For the mid-term period (2031-2050), the mean increase, compared to the reference period of 1986-2005, over both scenarios (RCP 4.5 & RCP 8.5) is 160 degree-days. There is no significant difference between the both scenarios. However, for the long-term period (2081-2100), the two scenarios present very significant differences. A rise of 685 degree-days is expected with RCP 8.5 while the rise is only 280 degree-days with RCP 4.5.

Table 4: Predicted evolution of the Huglin Index

	Huglin index (degree.days)					
	MEAN	MAX	MIN	Max-Min	SD	Difference/historical period
Historical period (1986-2005)	2196	2242	2131	111	22.5	
RCP 4.5 (2031-2050)	2352	2397	2285	112	22.9	155
RCP 8.5 (2031-2050)	2358	2404	2292	112	22.8	162
RCP 4.5 (2081-2100)	2476	2521	2409	112	23.1	280
RCP 8.5 (2081-2100)	2882	2927	2814	113	23.6	685

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 18 and 19) for Merlot by using the Grapevine Flowering and Veraison model (GFV) (Parker 2011,2013).

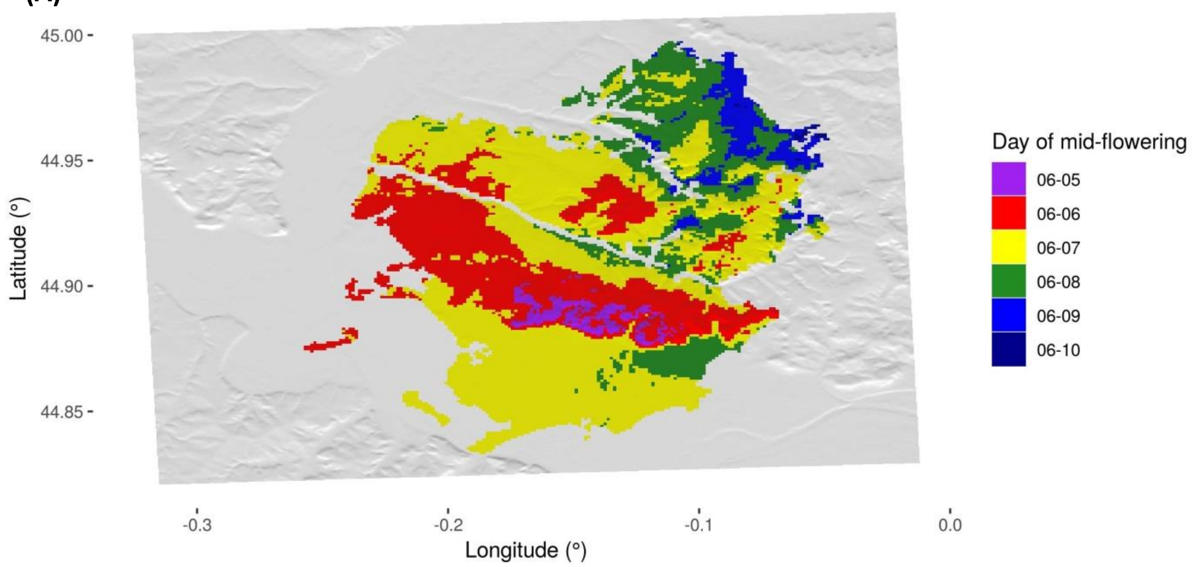
The historical maps (1986-2005) of flowering and veraison highlight the strong link between temperature (as measured by bioclimatic indices) and the timing of phenological stages. The phenologically-advanced areas (limestone plateaus, south facing slopes and western parts) are those with the higher bioclimatic indices (Figures 18 and 19). During the historical period, the spatial range in the timing of phenological events is 5 days for flowering and 8 days for veraison, with the mean mid-flowering period being around the 7th of June, and mid-veraison around the 11th of August (Table 5).

Like for the Huglin index, the spatial amplitudes of mid-flowering and mid-veraison over this area for whichever scenario and period considered are the same, around 5 days for mid-flowering and 7 days for mid-veraison.

The evolution at mid term (2031-2050) of the timing of phenology will be around 3 to 5 days for mid flowering and 5 to 7 days for mid-veraison.

In the long term, phenology modelling results demonstrate major changes and significant differences between the two scenarios. For mid-flowering, this evolution varies from 5 days (RCP 4.5) to 14 days (RCP 8.5). For mid-veraison, an advance of 9 days is found for RCP 4.5 and 20 days for the scenario 8.5.

(A)



(B)

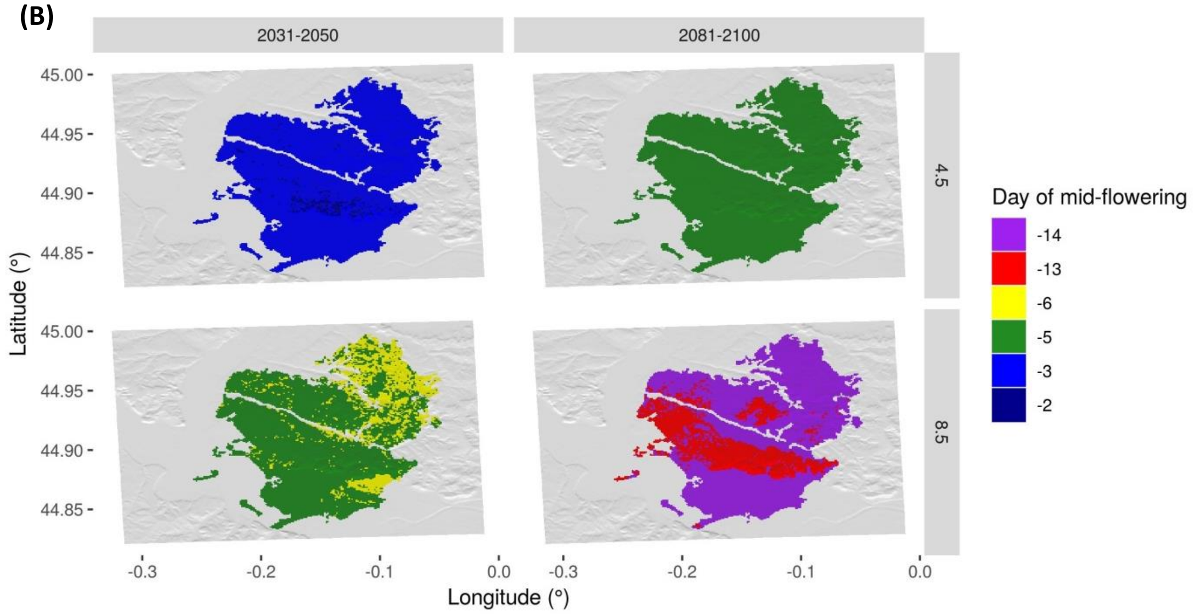


Figure 18: GFV modelling of the changes in the timing of the mid-flowering of Merlot in the Pomerol/Saint Emilion area in 2031-2050 and 2081-2100, according to scenarios RCP 4.5 and RCP 8.5 (B), relative to the historical period 1986-2005 (A)

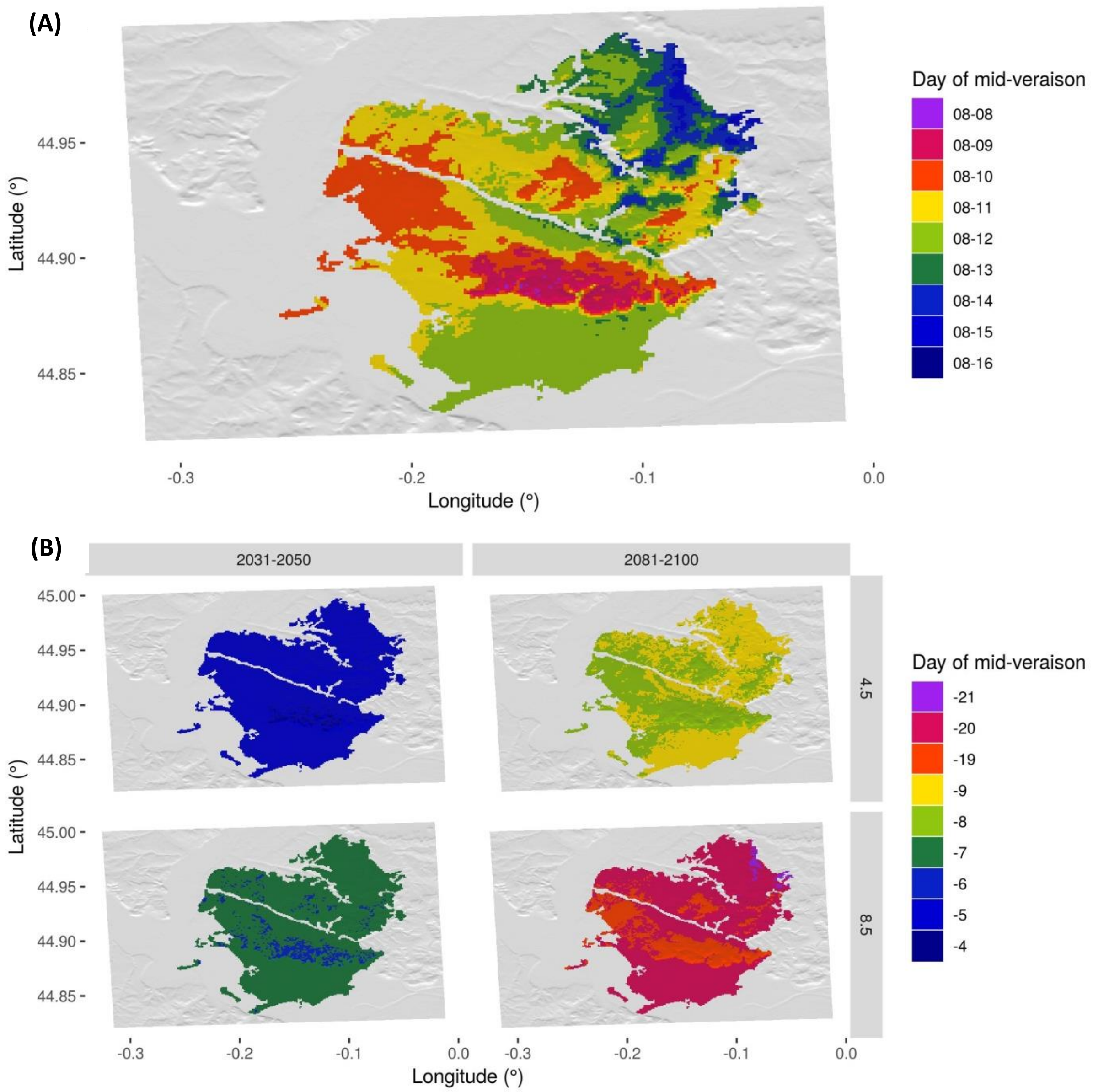


Figure 19: GFV modelling of the changes in the timing of the mid-veraison of Merlot in the Pomerol/Saint Emilion area in 2031-2050 and 2081-2100, according to scenarios RCP 4.5 and RCP 8.5 (B), relative to the historical period 1986-2005 (A)

Table 5: Prediction of the changes in the dates and spatial variation of mid-flowering and mid-veraison for two climate change scenarios

	Day of the year of mid_flowering of Merlot					
	MEAN	MAX	MIN	Max-Min	SD	Difference/historical period
Historical period (1986-2005)	158	161	155	5	0.9	
RCP 4.5 (2031-2050)	155	158	153	5	0.8	-3
RCP 8.5 (2031-2050)	152	155	150	5	0.8	-5
RCP 4.5 (2081-2100)	152	155	150	5	0.8	-5
RCP 8.5 (2081-2100)	144	146	142	4	0.7	-14
	Day of the year of mid_veraison of Merlot					
	MEAN	MAX	MIN	Max-Min	SD	Difference/historical period
Historical period (1986-2005)	223	227	220	8	1.3	
RCP 4.5 (2031-2050)	218	222	215	7	1.2	-5
RCP 8.5 (2031-2050)	216	220	213	7	1.2	-7
RCP 4.5 (2081-2100)	214	218	212	7	1.2	-9
RCP 8.5 (2081-2100)	203	207	201	6	1.0	-20

Conclusion part 2

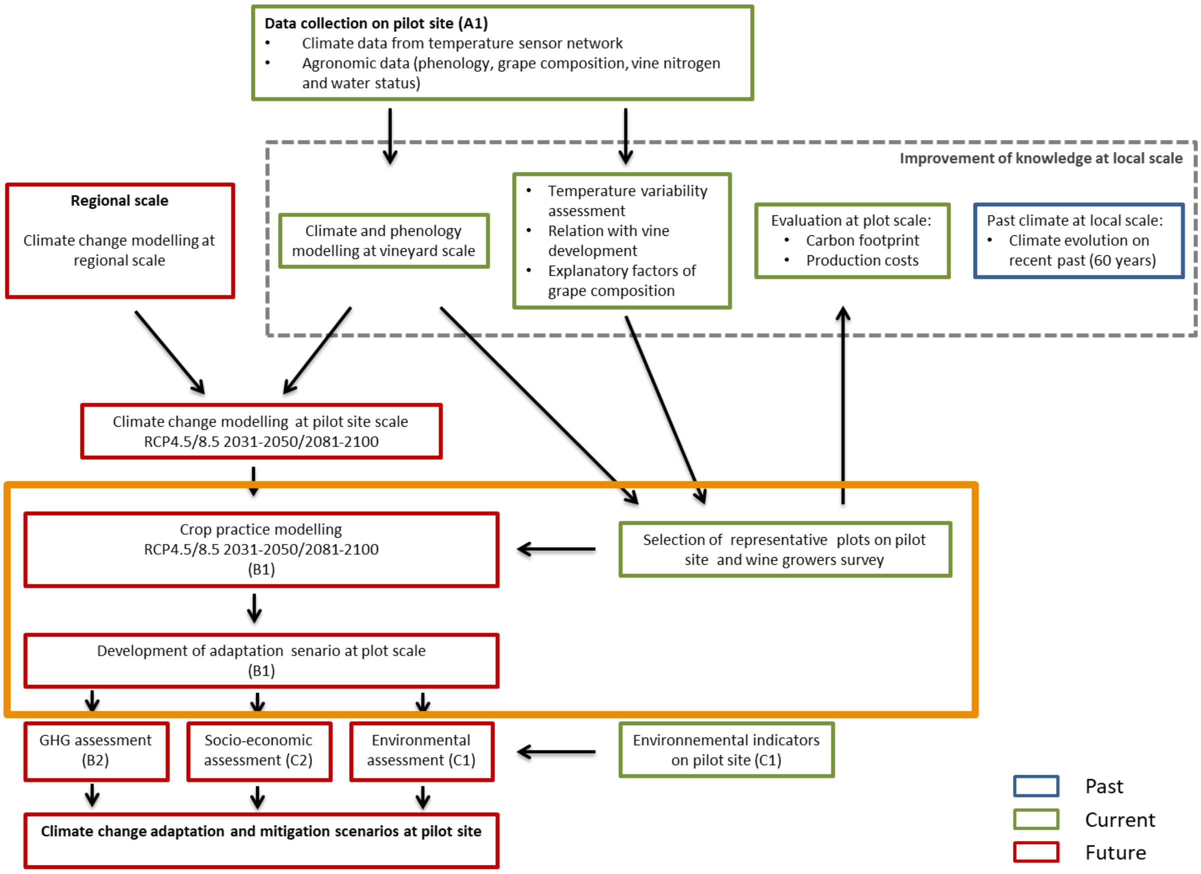
One of the major results of this part of the report is to demonstrate the feasibility of mapping the evolution of climate change and the consequences on vine development at the vineyard scale.

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.

The model does not demonstrate any significant differences 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 (+685 degree-days in Huglin Index for RPC 8.5 and + 280 degree-days for RCP 4.5), 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 15 representative plots in the Saint-Emilion/Pomerol pilot site. The objective of this part is to show trends in the timing of phenological stages and to analyse changes in agronomic practice by comparing a set of representative plots. Based on this information, possible changes in practices according to different climate scenarios can be assessed.

3.1 The selection of representative plots

15 representative plots were selected from the 90 plots where temperature sensors were installed in the trial area, based on temperature, environment, economic, social and technical criteria (Figure 20).

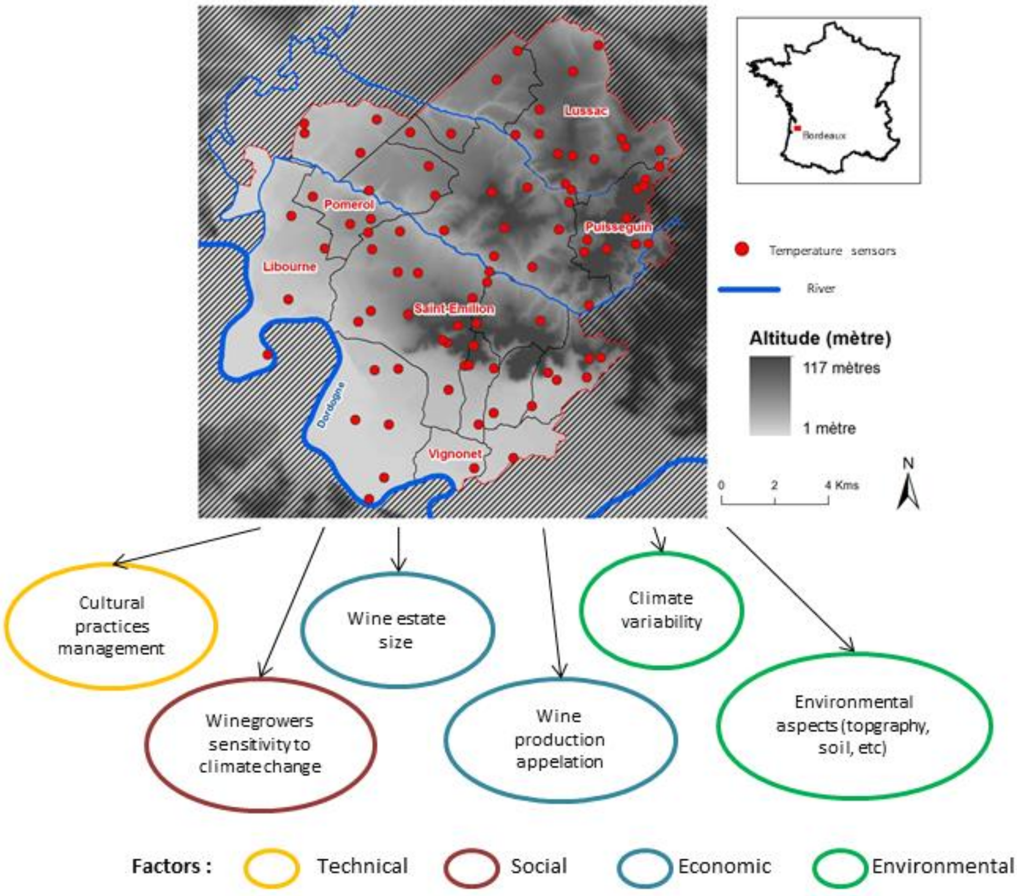


Figure 20: Major criteria for the selection of representative plots

The sampling was decided according to several criteria. First, plots with temperature sensors were selected, in order to integrate climatic variability data in the model. The geographical distribution of the plots was analysed, so as to choose a sample with representative environmental variability. Altitude, soil, climate as well as latitude and longitude of the plots were taken into account. The cultural practices used in the plots were also recorded, in order to integrate the diversity of practices and materials used in these appellations. Economic factors were included by selecting representative wine estates and appellations from the pilot site. Finally, winemakers with an awareness of the effect of climate change were preferentially contacted.

3.2 Plot characteristics

15 plots were selected from the Saint-Emilion/Pomerol pilot site (Figure 21).

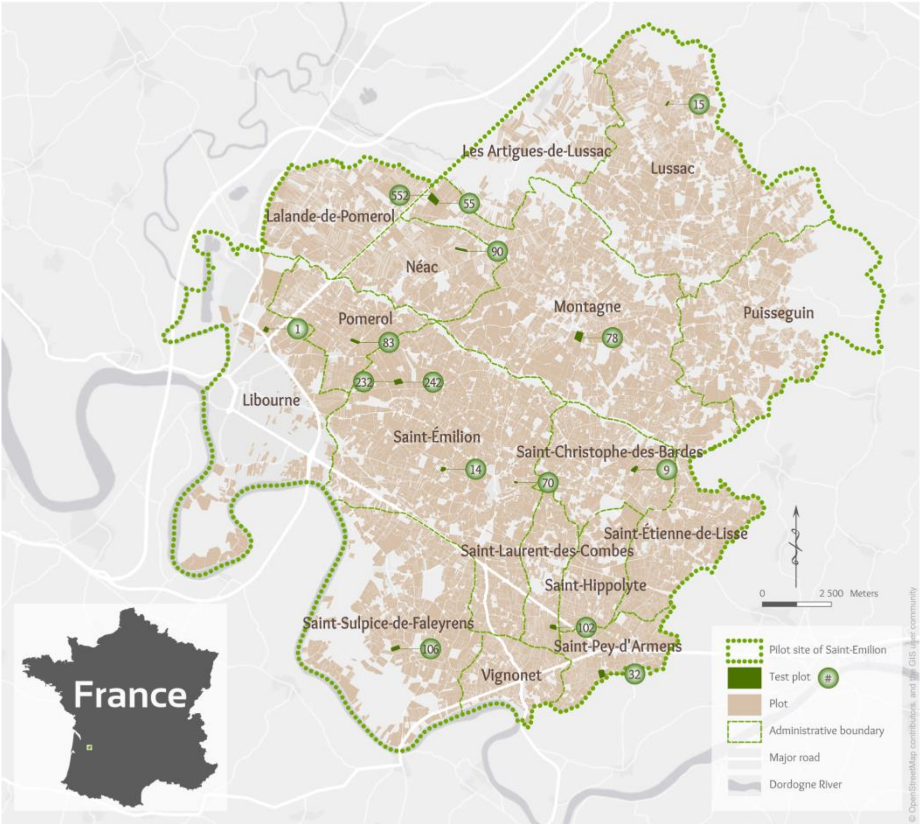


Figure 21: Selected plots in the Saint-Emilion/Pomerol pilot site

The characteristics of the different plots are described in Table 6.

Table 6: Characteristics of the representative plots

	Wine estate	Elevation (m)	Winkler (Avg 2012-2017	Appellation	Conventional / Organic	Inter row plant cover surface
Plot 1	MAZ	18	1847	Pomerol	Organic	Bare soil
Plot 9	LAP	71	1798	Saint-Emilion Grand Cru	Conventional	Entire surface
Plot 14	COU	60	1925	Saint-Emilion Grand Cru	Conventional	Alternative
Plot 15	GRE	67	1771	Lussac-Saint-Emilion	Conventional	Alternative
Plot 32	LAV	10	1781	Saint-Emilion	Conventional	Entire surface
Plot 55	LYC	39	1786	Montagne-Saint-Emilion	Conventional	Alternative
Plot 552				Montagne-Saint-Emilion	Organic	Alternative
Plot 70	TRO	84	1876	Saint-Emilion 1er Grand Cru classé B	Conventional	Alternative
Plot 78	LAC	78	1819	Montagne-Saint-Emilion	Conventional	Entire surface
Plot 83	CDM	35	1828	Pomerol	Conventional	Alternative
Plot 90	YVE	45	1799	Lalande de Pomerol	Conventional	Entire surface
Plot 102	BAR	10	1714	Saint-Emilion Grand Cru	Conventional	Entire surface
Plot 106	GES	6	1780	Saint-Emilion Grand Cru	Conventional	Alternative
Plot 232	CB	38	1849	Saint-Emilion 1er Grand Cru classé A	Conventional	Entire surface
Plot 242				Saint-Emilion 1er Grand Cru classé A		Bare soil

The elevation of the selected plots varies from 6 to 84 metres, which is representative of the pilot site (0 to 117 metres). Climate variability is also representative, with the average

Winkler Index varying from 1714 to 1925 degree-days between 2012 and 2016. The amplitude registered by the selected plots is 211 degree-days, which is close to that of the pilot site (average amplitude: 285 degree-days).

On two of the wine estates, two adjoining plots were selected in order to compare two different cultural practices. In the “CB” wine estate, different vineyard floor management strategies were compared between two plots. Plot 232 has cover crop over the entire inter-row surface, whereas the inter-row surface on the second plot (242) is uncovered (cultivated bare soil). In the “LYC” wine estate, plot 55 is managed using conventional crop protection techniques, whereas plot 552 is managed with organic crop protection.

3.3 Vinegrower surveys

Grower surveys were conducted using questionnaire Q3 (please see Annex B2_1 in the progress report). All interventions with tools, inputs and equipment carried out in 2016 were recorded for each plot.

3.4 The SEVE model prototype

In order to assess potential future adaptation trends, a specific prototype of the SEVE (Simulating Environmental impacts on Viticultural Ecosystems) model was implemented and in the 15 representative plots. The baseline of SEVE model was adapted to local constraints and the agronomic characteristic of Saint-Emilion vineyards. Simulated results can be viewed using the graphical user interface, or through the *postgresl/postgis* database coupled with the SEVE model.

3.4.1 Phenological cycle and agronomic action modelling

The results from this modelling are shown in the form of dynamic graphs, which allow key information to be quickly visualised at the plot scale. The results of the modelling of phenological cycles are comparable to those provided by Action A1. The changes in the timing of phenological stages reflect a significant evolution between the first (2031-2050) and the second period (2081-2100), particularly for scenario 8.5.

The Saint-Emilion/Pomerol pilot site is particularly complex to study because of the high diversity of practices in the same regulated appellation area. In this context, the SEVE model tends to underestimate agronomic actions such as soil cultivation, which can have several different objectives (including managing water deficit, weed control, soil structure improvement, and the activation of soil microorganisms).

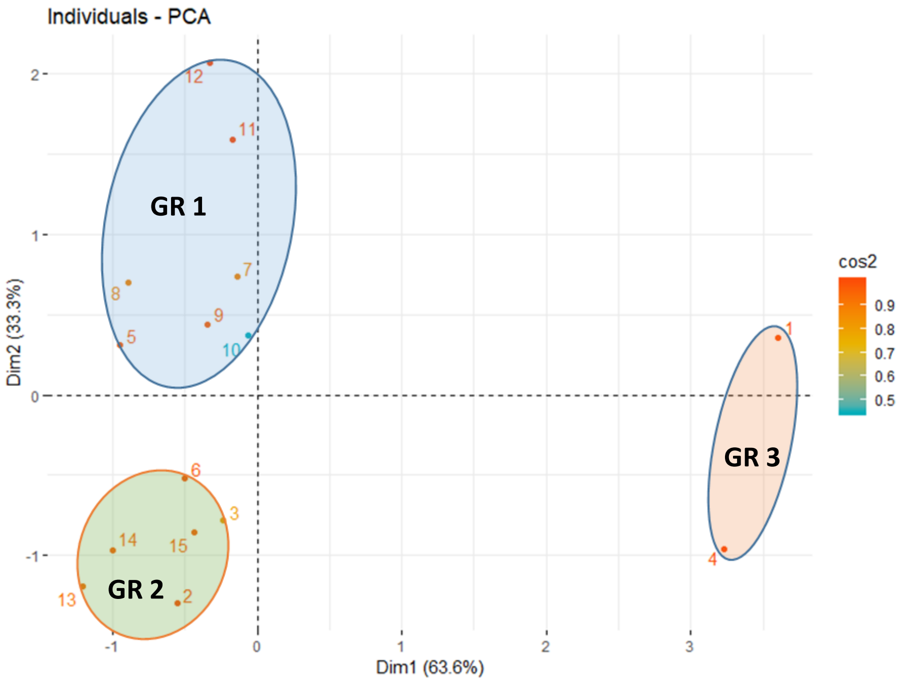
3.4.2 Analysis of the differences between plots

To compare the 15 representative plots, a Principal Component Analysis (PCA) was carried out (see Figure 22), using the following data:

- bioclimatic index values

- the number of agronomic interventions
- maximum soil water holding capacity

Three groups can be distinguished. The first group (GR1) contains the warmer plots with the greatest changes in their phenological cycles. The second group (GR2) includes the cooler plots, which will be less impacted by warming temperatures. The third group (GR3) includes plots that will see a significant increase in the number of phytosanitary treatments in the future. Both plots of this group are organically managed plots.



ACP number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Plot	Plot 1	Plot 15	Plot 55	Plot 552	Plot 78	Plot 90	Plot 83	Plot 9	Plot 242	Plot 232	Plot 70	Plot 14	Plot 102	Plot 32	Plot 106

Figure 22: result of a principal component analysis of the 15 selected plots in the pilot site

Using these results, the mean from each group was calculated for further study.

3.4.3 In-depth analysis of the representative plots

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 (Parker et al, 2020). These results (Table 7) present minimum, median and maximum date of maturity when the model reach 220g/l for each scenario. Significant change can be noticed in the timing of the main phenological stages, reflecting an earlier maturation of the grapevine berries in the later periods, especially during the period 2081-2100 for the scenario 8.5. Maturation date for the Merlot variety could advance until 1 august for the hotter years of this scenario for the plots of Group 1.

Differences of maturity date can be detected between all the plots, with variability from 4 to 5 days between the earlier and the latest plots for each scenario. The model is reducing the variability inside the pilot site and selected plots are not representing exactly the extreme values of this area. Calculation of the average date for each group left out extreme values.

Table 7: Mean of maturity date minimum, maximum and average for each group of plot

		Maturity of Merlot (220 g/l of sugar content)					
		RCP 4.5			**RCP 8.5**		
		min	median	max	min	median	max
2031-2050	**GR1**	19 aug	25 aug	30 aug	15 aug	25 aug	28 aug
	GR2	21 aug	27 aug	2 sep	17 aug	27 aug	31 aug
	GR3	20 aug	26 aug	1 sep	17 aug	26 aug	30 aug
2081-2100	**GR1**	15 aug	22 aug	28 aug	1 aug	8 aug	15 aug
	GR2	17 aug	23 aug	30 aug	3 aug	10 aug	17 aug
	GR3	16 aug	22 aug	29 aug	2 aug	8 aug	16 aug

Then, the agronomic intervention workflow, simulated by the SEVE model, was analysed. The results show only a small change in agronomic interventions, despite significant differences in the timings of phenological events. The small difference between data provided by regionalised climate models does not allow to integrate local variability between plots. Key information, such as humidity or precipitations, are more specifically concerned by this problem. These limitations do not allow to simulate the variability of specific agronomic actions such as soil cultivation or inter-row cover crop management. Despite this limitation, the changes in phytosanitary treatment practices have been simulated. These results show an increase in the number of phytosanitary treatments, particularly in the long term period (Table 8), reflecting a future potential increase in disease pressure. This evolution is resulting from the increase of temperature and relative humidity providing by regional climate downscaling models (Cordex).

During the mid-term period (2031-2050), no significant changes can be detected for plots from group 1 and 2. The number fungicide treatment increase during the period 2081-2100 for these plots, with average of 4 more treatments. This increase is more important for organical plots from group 3, with 5 more treatment during the 2031-2050 and 11 more treatment during the period 2081-2100.

Table 8: evolution of the number of fungicide treatment between 2016 and the 4 scenarios

	2016	**2031-2050**		**2081-2100**	
Scenarios		**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP8.5**
GR1	**10**	10	11	14	15
GR2	**12**	10	11	14	14
GR3	**19**	24	25	30	30

3.4.4 Potential adaptation scenarios

Potential adaptation scenarios were first defined according to vineyard characteristics and current agronomic practices.

These scenarios have been implemented in the SEVE model as decision rules; for example, adaptations in winemaking techniques can be used as long as the limit of vine variety adaptation is not reached. Regarding adaptation through the choice of plant material, several parameters are used, such as maturity date in previous years, the age of the vine, and the vine variety permitted in the wine-producing area for the production of quality wine. To define the date of replacement for grape variety, the threshold was set at 4 years /10 where theoretical maturity (220 g/l sugar) has been reached before 23rd august. Table 9 shows the recommendations (according to the SEVE model) for the conversion of grape varieties for the three test plots, according to different time periods and scenarios.

Table 9: vine varietal changes recommended on the selected plots in order to adapt to different time periods and scenarios

		4.5		**8.5**	
	name	date of replacement	New grape variety	date of replacement	New grape variety
2030-2050	**Plot 1**	2040	Cabernet franc	2039	Cabernet-Sauvignon
	Plot 15	2044	Cabernet franc	2044	Cabernet franc
	Plot 55	2044	Cabernet franc	2044	Cabernet franc
	Plot 552	2044	Cabernet franc	2044	Cabernet franc
	Plot 78	2039	Cabernet franc	2041	Cabernet-Sauvignon
	Plot 90	2044	Cabernet franc	2044	Cabernet franc
	Plot 83	2039	Cabernet franc	2040	Cabernet-Sauvignon
	Plot 9	2039	Cabernet franc	2040	Cabernet-Sauvignon
	Plot 242	2039	Cabernet franc	2040	Cabernet-Sauvignon
	Plot 232	2039	Cabernet franc	2040	Cabernet-Sauvignon
	Plot 70	2037	Cabernet franc	2036	Cabernet-Sauvignon
	Plot 14	2037	Cabernet franc	2035	Cabernet franc
	Plot 102	2044	Cabernet franc	2044	Cabernet franc
	Plot 32	2044	Cabernet franc	2044	Cabernet franc
	Plot 106	2044	Cabernet franc	2044	Cabernet franc
	name	date of replacement	New grape variety	date of replacement	New grape variety
2080-2100	**Plot 1**	2092	Petit verdot	2084	Carmenère
	Plot 15	2093	Cabernet-Sauvignon	2084	Carmenère
	Plot 55	2093	Cabernet-Sauvignon	2084	Carmenère
	Plot 552	2093	Cabernet-Sauvignon	2084	Carmenère
	Plot 78	2096	Petit verdot	2084	Carmenère
	Plot 90	2093	Cabernet-Sauvignon	2084	Carmenère
	Plot 83	2096	Petit verdot	2084	Carmenère
	Plot 9	2096	Petit verdot	2084	Carmenère
	Plot 242	2096	Petit verdot	2084	Carmenère
	Plot 232	2096	Petit verdot	2084	Carmenère
	Plot 70	2090	Petit verdot	2084	Carmenère
	Plot 14	2090	Petit verdot	2084	Carmenère
	Plot 102	2093	Cabernet-Sauvignon	2084	Carmenère
	Plot 32	2096	Cabernet-Sauvignon	2084	Carmenère
	Plot 106	2096	Cabernet-Sauvignon	2084	Carmenère

Other possible adaptations are strongly linked to changes in water availability. 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 be focused 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.

3.4.5 Frost risk

The Saint-Emilion/Pomerol pilot site has been subject to 2 generalized spring frosts over the last 30 years, with significant losses of crop. In the future, this climatic event can be more frequent with climate change.

The model has evaluated frost risk occurrence in the future when negative temperature are recorded during budburst. Results are quite similar for each plot. Table 10 shows an increase of the frost risk during the period 2081-2100 with an average of 3 years of frost on the 20 years for the scenario RCP 4.5 and 1 year of frost on the 20 years for the scenario 8.5. The period 2031-2050 has recorded 0 years of frost for both scenarios.

For period 2081-2100 RCP 4.5, budburst period is much earlier than for period 2031-2050, which can explain this increase. For the scenario 2081-2100 8.5, temperature is warmer and is reducing the frost risk.

This will mean changes for the Saint-Emilion/Pomerol pilot site, where a large number of winegrowers will need to adjust their practices and their frost protection system.

Table 10: Frost risk for the Saint/Emilion pilot site, according to SEVE model results for the 2030-2050 and 2080-2100, in the 4.5 and 8.5 scenarios

Scenarios	**2030-2050**	**2080-2100**
RCP 4.5	0	3
RCP 8.5	0	1

Conclusion to part 3:

The results presented in this section demonstrate that the SEVE model is able to integrate vinegrowing and agronomic choices and practices with climate variability.

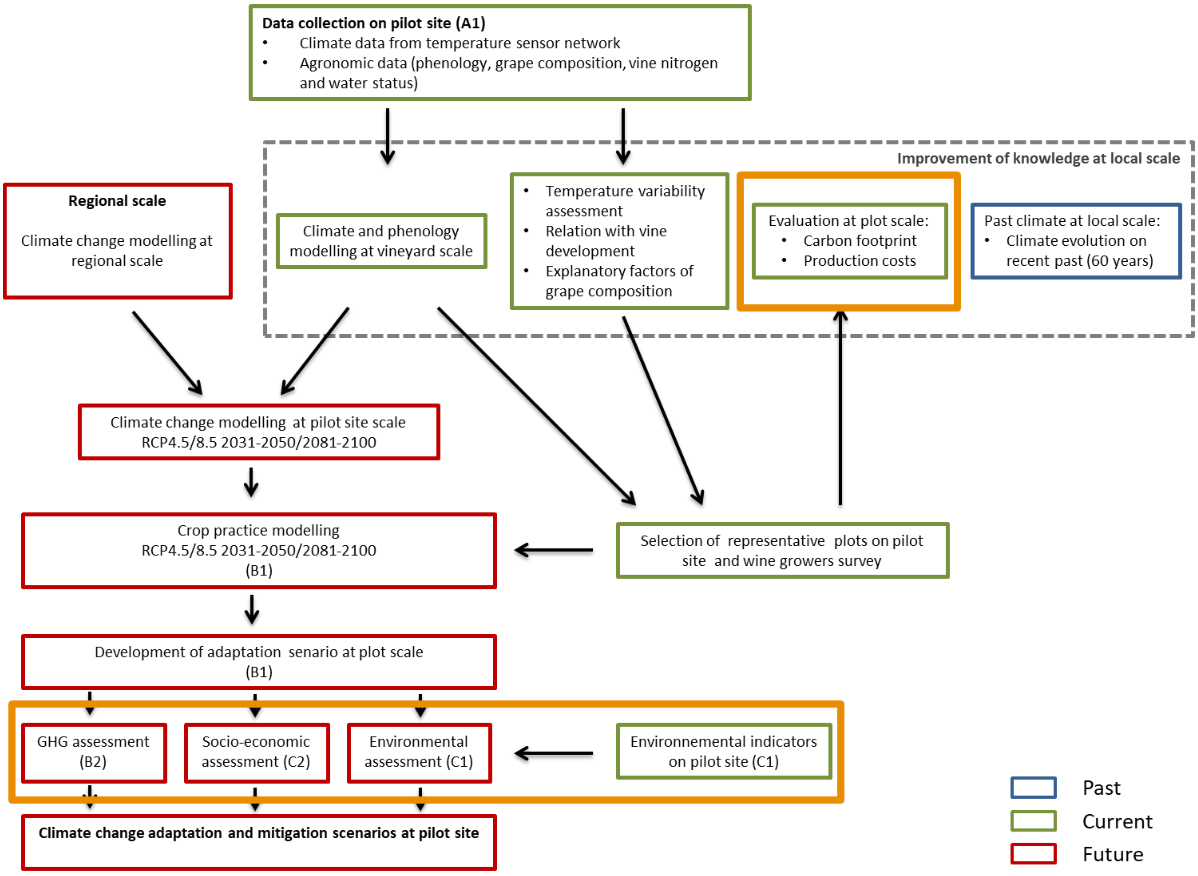
The key findings are:

- Phenology cycle changes are effectively integrated into the SEVE model, with simulation results comparable to outputs provided by the geostatistical model presented in part 2.

- 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 phytosanitary 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: SUSTAINABILITY ASSESSMENT OF CURRENT AND FUTURE VITICULTURAL PRACTICES



The preceding part of this report investigated the evolution of viticultural practices on the Saint-Emilion/Pomerol pilot site and different viticultural adaptation scenarios. These changes can affect the environmental footprint or the socio-economic conditions of the vinegrowers. The potential impact of these scenarios on the environment and on production costs are discussed in this part of the report. Current environmental indicators at pilot site scale were defined, and 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 assessment

The objective is to evaluate GHG emissions for each current cultural practices on the 15 representative plots. In this report, results were based on cultural practices implemented in 2016. GHG emission assessment provides information to vinegrowers on the environmental impact of their practices and enables them to evaluate potential mitigation strategies.

4.1.1 Current GHG emissions at plot scale

A GHG emission calculation methodology has been applied for the cultural year 2015-2016, on the 15 plots of Saint-Emilion/Pomerol pilot site, monitored for their vineyard practices. All the elements taken into account are listed in the Action B2 deliverable of the project. This methodology was designed to identify:

- the most GHG-emitting management strategy among the sampled plots
- the most GHG-emitting vineyard operations
- the major types of GHG emissions

The accuracy of these calculations allows us to assess potential levers which can be used by vinegrowers in terms of GHG attenuation.

4.1.1.1 GHG emissions per plot

Figure 23 demonstrates the great variability in GHG emissions between the 15 plots. The emission level of the most emitting plot (n°552: 3000 kg eq CO_2/ha/year) is three times more than the emission level of the least emitting plot (n°90: 1180 kg eq CO_2/ha/year).

The average is 1860 kg eq CO_2/ha/year (standard deviation = 665).

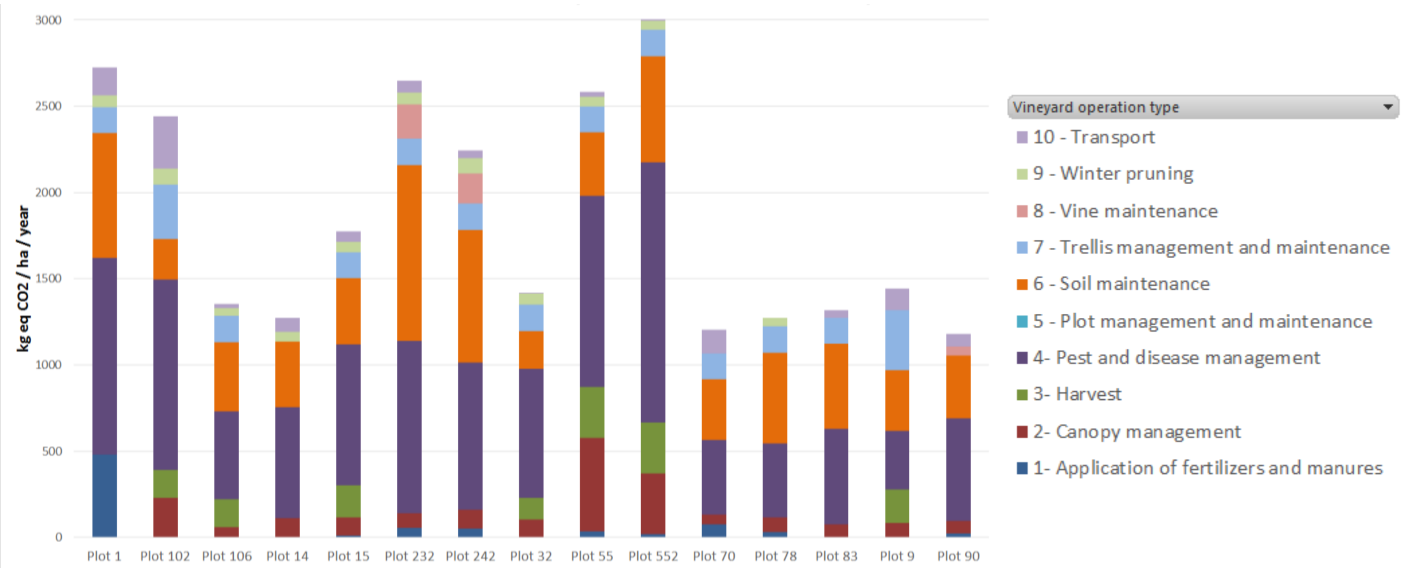


Figure 23: Total GHG emissions for each plot, categorised by viticultural operation

The two main GHG-emitting vineyard operations are:

- pest and disease management (between 23 and 53% of the total emissions per plot).

- soil maintenance (between 10 and 38 % of total emissions per plot)

Harvest can be a significant part of the total emissions if this operation is not manual (between 7% and 14% of the total emissions of each plot). The application of organic or mineral fertilisers and canopy management (summer pruning and shoot positioning) can also contribute significantly to the total GHG emissions.

The variability of these results from plot to plot can be explained by the number of days taken per vineyard operation, and by the power of the tractors used. For example, the same tractor power (150 hp) is used for pest and disease management in plots 55 and 552, but plot 55 has less operational days (respectively 11 and 16 days), resulting in a difference of 400 kg eq CO_2/ha/year between the two plots. On the other hand, plots 55 and 106 have the same number of intervention days for pest and disease management, but the motor power of the tractors used for spraying pesticides is different. This is 65 hp for plot 106, but 150 hp for plot 55 (as the harvesting machine is adapted for pesticide application), resulting in a difference of 600 kg eq CO_2/ha/year.

The "Transport" operation can generate significant GHG emissions, depending on the distance to the farm, the number of mechanical interventions and the number of workers used for manual interventions.

4.1.1.2 GHG emissions per intervention

The GHG emissions per intervention of each vineyard type and each plot have been calculated. The figure below shows the mean of these indicators for the whole plot sample (Figure 24).

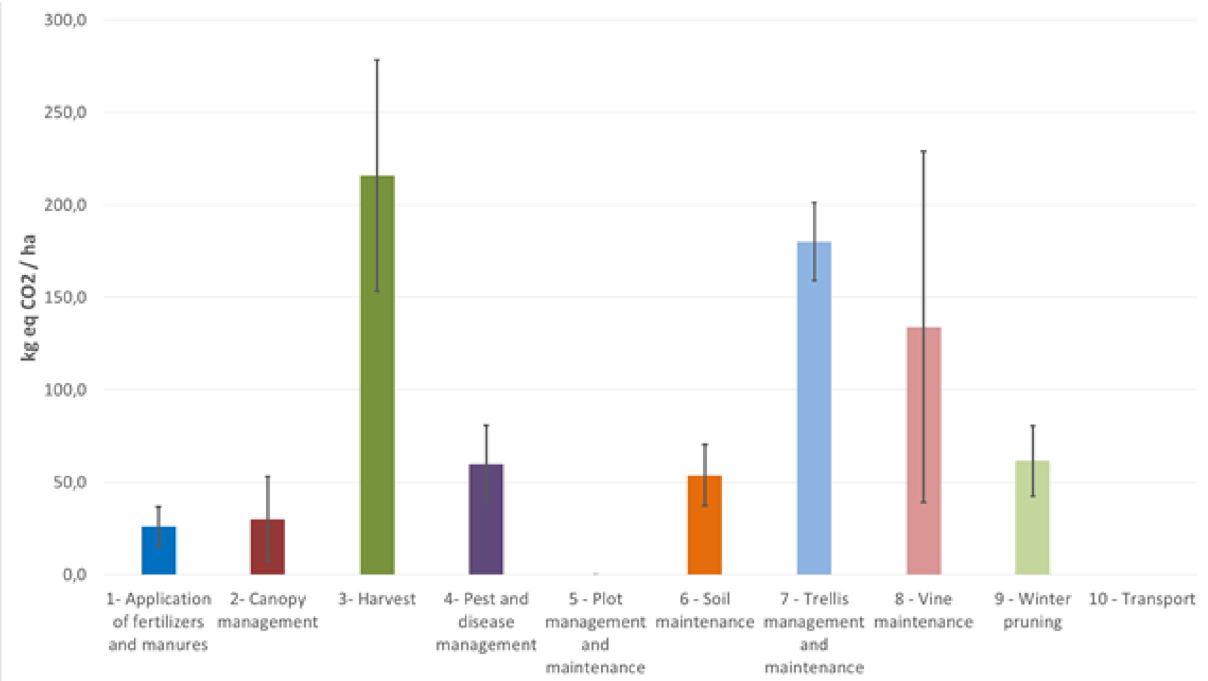


Figure 24: Mean of GHG emissions per single operation for each vineyard intervention (direct and indirect emissions)

When broken down into single operations per intervention, harvest and trellis management are the most GHG-emitting vineyard operations with emissions of around 90 kg eq CO_2/ha. Harvest is typically carried out using machines with high engine power. Trellis management and vine maintenance also have high GHG emissions because they can be mechanised.

Pest and disease management and soil maintenance, which are the most emitting practices throughout the cultural year, emits around 30 kg eq CO_2/ha for one intervention.

4.1.1.3 Direct and indirect emissions

The difference between direct and indirect GHG emissions were calculated for each plot (see Figure 25). 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. Direct emissions account for between 57 and 77% of the total emissions of each plot.

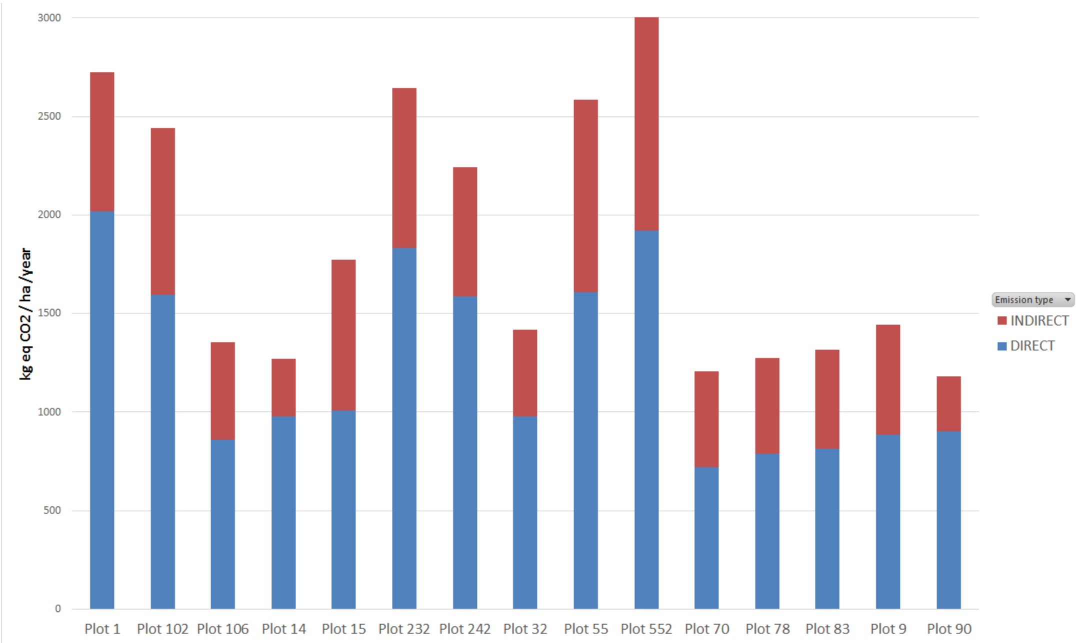


Figure 25: Total direct and indirect emissions per plot

Figure 26 illustrates the GHG emission results for plots 1 (Gr3), 15 (Gr2) and 70 (Gr1), for the growing year 2015-2016.

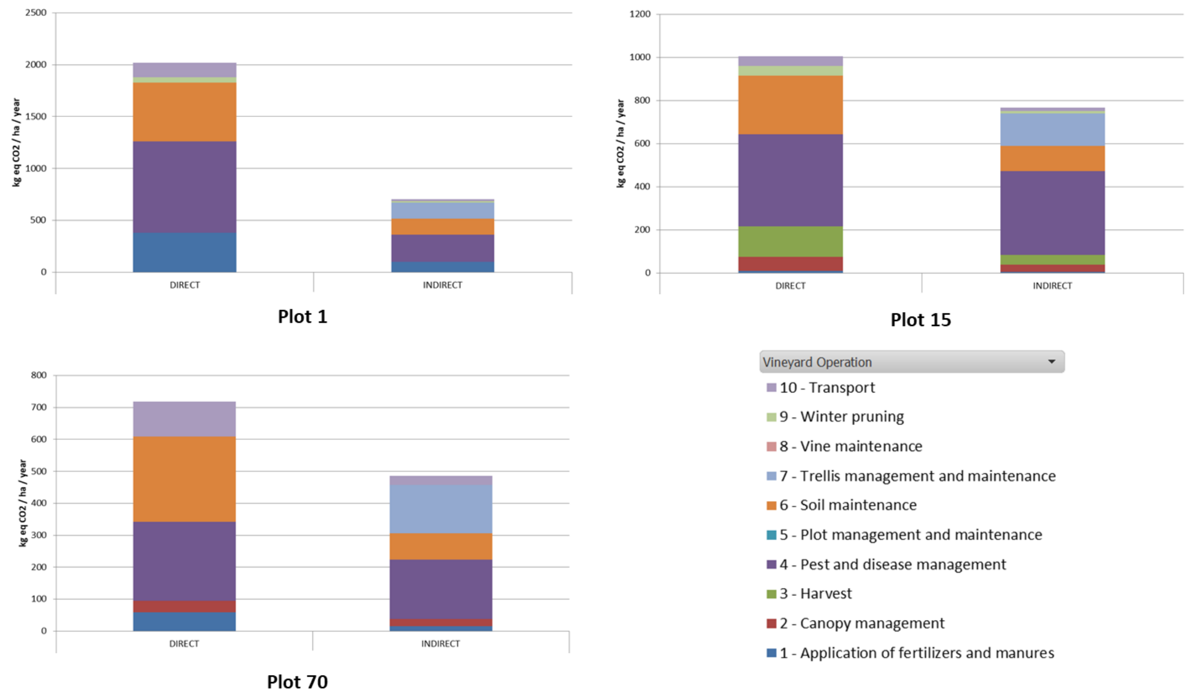


Figure 26: Direct and Indirect GHG emissions assessment by interventions for plots 1, 15 and 70 in the 2015-16 growing season

The split between direct and indirect emissions depends on the vineyard operation. Some vineyard operations, like pest and diseases management or trellis management, involves inputs or equipment that do not themselves produce any GHG emissions in the field, but generate significant indirect emissions.

For the three plots, pest and disease management generates the most direct and indirect GHG emissions. Soil maintenance and transport emits a lot of direct GHG emissions as well. On the other hand, the level of indirect emissions generated by trellising equipment is significant, even after having smoothed the emissions generated by the manufacturing process over the whole lifetime of the machines used.

4.1.2 Greenhouse gas emissions estimation of adaptation strategies to climate change

4.1.2.1 Methodology for assessing the strategies

Potential climate change adaptation strategies are listed in Table 9.

As explained in Part 3, 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). These adaptation actions were screened, taking into account a range of GHG emission drivers (Table 11). The results show that most of the adaptation strategies do not have any significant consequence on GHG emissions (particularly at a multi-year scale), or are not taken into account by the SEVE model. Only a few of them have potential consequences on GHG emissions and are taken into account in the SEVE model (for example irrigation).

Table 11: GHG emission screening of a range of climate change adaptations strategies

Adaptation strategies	Agronomic measure	Intervention/Equipment	Explicitation of the change	Consequence on the GHG emissions	Included in SEVE model ?
Technical operations management	Canopy management practices	Late spur-pruning	Date of intervention	No	No
		Increasing vine trunk height	Vine shape	No	No
		Trimming shoots or removing leaves	Number and type of interventions	Yes	Yes
	Soil management practices	Soil tillage techniques	Number and type of interventions	Yes	Yes, but results to take with cautious
		Cover cropping species selection	Input type	Yes	No
	Management of frost risks	Early pruning	Date of intervention	No	No
		Wind machines or heaters	New equipment	Yes	No
Winemaking practices		Dealcoholization	New equipment and energy consumption	Yes	Out of the scope of the project
Plant material adaptation	Choice of grape clone/local grape variety	Grafting	One shot new intervention	Insignificant on a pluriannual scale	Yes
	Choice of rootstock	Plantation of a new rootstock	One shot new intervention	Insignificant on a pluriannual scale	No
	Choice of non local grape variety	Grafting	One shot new intervention	Insignificant on a pluriannual scale	Yes
Vine training system	Canopy management practices	Gobelet pruning method	Type of intervention	No	No
Shading systems	Drought management	Solar shading systems in vine	New equipment	Yes	No
Irrigation	Water supply management	Drip irrigation system	New equipment and energy consumption	Yes	Yes

The only significant adaptation strategy that was generated by the simulation models is an increase in the number of fungicide treatments, which increased significantly over the period 2081-2100. Therefore, the estimation of GHG emissions related to adaptation scenarios to climate change only focused on pest and disease management. However, these results must be handled with caution as they do not take into account all the potential changes expected in the future. The only parameter that changes in those scenarios is the number of interventions; the other parameters (type of active ingredients, motor power of vineyard tools) are impossible to estimate.

4.1.2.2 Results of GHG emissions of scenarios

Current GHG emissions at plot scale have shown that pest and disease management is one of the most emitting practices during a year by representing between 23 and 53% of the total emissions per plot. A significant increase of these treatments is predicted by SEVE model during the period 2081-2100 for all plots. The evolution of fungicide treatment is very variable between plots, which not allow us to calculate with precision GHG emissions for this scenario. Predicted GHG emissions for pest management for each plot over the years 2080-2100 will be higher compared to the year 2016. 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 the sensitivity of grape varieties to disease pressure is similar from one grape variety to another. Indeed, the parameters of the new resistant varieties were not entered in the SEVE model. However, there is potential to work with these in further investigations, because they can significantly reduce GHG emissions.

4.2 Environmental assessment

The environmental impact of viticulture is quite complex. Alongside economic profitability, environmental sustainability has become a major factor in world viticulture and current legislation. European grapevine varieties are not resistant against the major fungal diseases powdery and downy mildew, leading to a high number of applications and use of fungicides. Herbicides are often used to manage the vineyard floor, and insecticides are used to control harmful insects. Due to climate change and worldwide trade and exchange, regional shifts in pest occurrences and new pests (such as the spotted wing drosophila) can be observed across Europe. Although disease monitoring and new management technologies have led to a reduction in the use of pesticides, soil management and plant protection measures lead to frequent tractor passes. Furthermore, vinegrowing regions are often monocultures, which have the potential to have negative effects on biodiversity. These observations illustrate that the interactions between viticulture and the environment are diverse. Action C1 has therefore defined several currently important environmental indicators, which can be used to assess and describe in detail these interactions.

The following general environmental assessment for Saint-Emilion/Pomerol pilot site describes the current situation concerning the most relevant environmental indicators. It contains a quantitative assessment for two typical plots (552 and 32), but this is not possible for all indicators.

4.2.1 Current environmental indicators in Saint-Emilion/Pomerol pilot site

4.2.1.1 Water quality

Water quality indicators were obtained from the *Schéma directeur d'aménagement et de Gestion des Eaux* (SDAGE, the French outline for the organization of the development and management of water resources) established by the law of 3 January 1992 on water management.

Water quality for surface water is defined by its ecological and chemical status. A good ecological status corresponds to a good functioning of aquatic ecosystems. It is measured through biodiversity indicators that compare the actual ecosystem with what would be the original biodiversity, without human intervention. Chemical status is defined by its levels of micro-pollutants, especially nitrates and pesticides.

The Saint-Emilion/Pomerol pilot site is crossed by the Barbanne River from east to west, which flows past Libourne, Pomerol, Saint-Emilion, Montagne and Puisseguin. In the SDAGE (2016-2021) Schedule of Adour-Garonne basin, the Barbanne has been classified to have a poor ecological status, with significant pesticide pressure (Figure 35). The Barbanne watershed is also classified as a vulnerable area by the Nitrate Directive n°91/676/CEE, which identifies the urgent need to reduce nitrate pollution from agriculture and viticulture. In this area, winegrowers are involved in an action plan that includes clear guidelines for the management of nitrogen fertilisation.

The Dordogne River, located to the south of this pilot site, is also classified as having poor ecological status, though the causative factors are unknown. However, six streams in this area are classified with medium or poor ecological status, the major pressure factors being pesticides, nitrates and the wastewater from water treatment plants.

The quality of groundwater is defined by chemical status, specially nitrates and pesticides, the two main groundwater pollutants. The major groundwater body on this pilot site is classified as 'good' in chemical status (Figure 27). The second one, on the north-west of the pilot site, is classified as 'very poor' chemical status, without information on the causative factors.

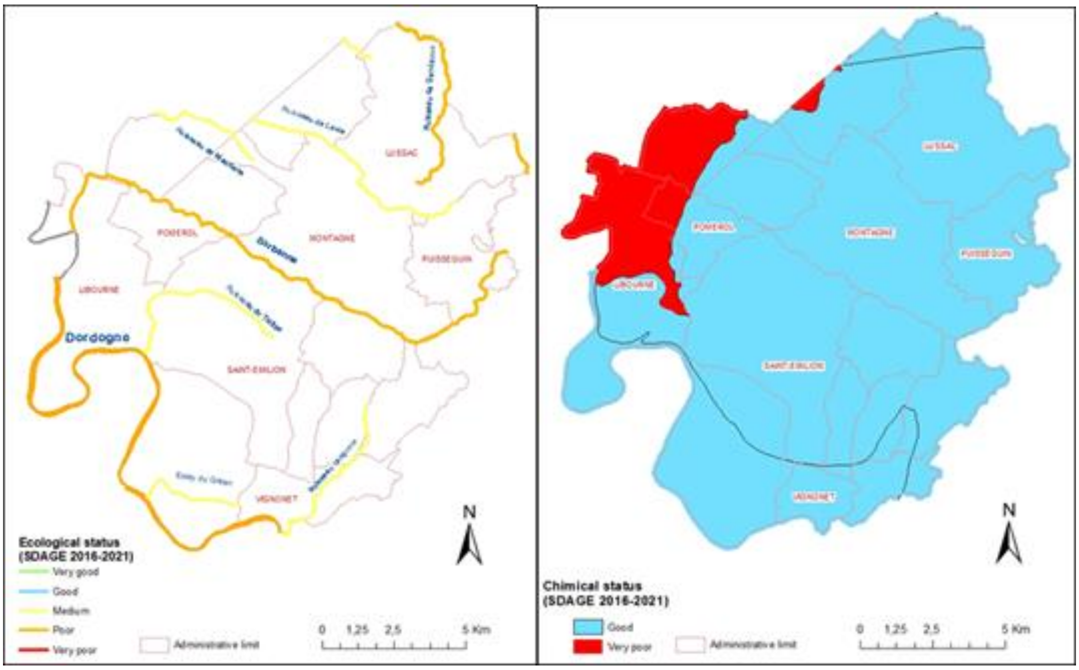


Figure 27: Ecological status of surface water (left) and chemical status of groundwater (right) on the Saint-Emilion/Pomerol pilot site (Data source: Water Agency - SDAGE Adour-Garonne 2016-2021)

To determine environmental indicators for representative plots, the evolution of the watershed ecological status where the plots are located can be analysed in future years (Table 12).

Table 12: Associates watersheds for the two representative plots, and their status

	Plot 552	**Plot 32**
Watersheds	Ruisseau de Maurienne	Ruisseau de Largrane
Ecological status	medium	medium

4.2.1.2 Water management

Concerning water management, the Saint-Emilion/Pomerol pilot site is not prone to vine water deficit, due to an annual rainfall of 790 mm (station Saint-Emilion, average 1994-2016). Only young vines, mainly planted on gravelly soil near Pomerol and Lalande de Pomerol, are vulnerable to drought stress. Therefore, the water footprint of viticulture is this area is very low.

4.2.1.3 Waste

The main waste generated by viticultural practices are linked to crop protection, such as spray tank washings. This area is highly regulated: vinegrowers have to manage their waste directly on their plot, or at a certified washing area, in order to recover and treat this kind of wastewater. French regulations also require that phytosanitary product packaging is recycled by registered companies. A reduction in the annual number of treatments will substantially decrease viticultural waste.

In the Saint-Emilion/Pomerol pilot site, the *Groupement de Défense contre les Organismes Nuisibles* (GDON: Group of Defence against Harmful Organisms) have measured treatment frequency indices (IFT in French) since 2010. These indicators calculate the number of approved applications per hectare applied on a plot during the growing season (Figure 28).

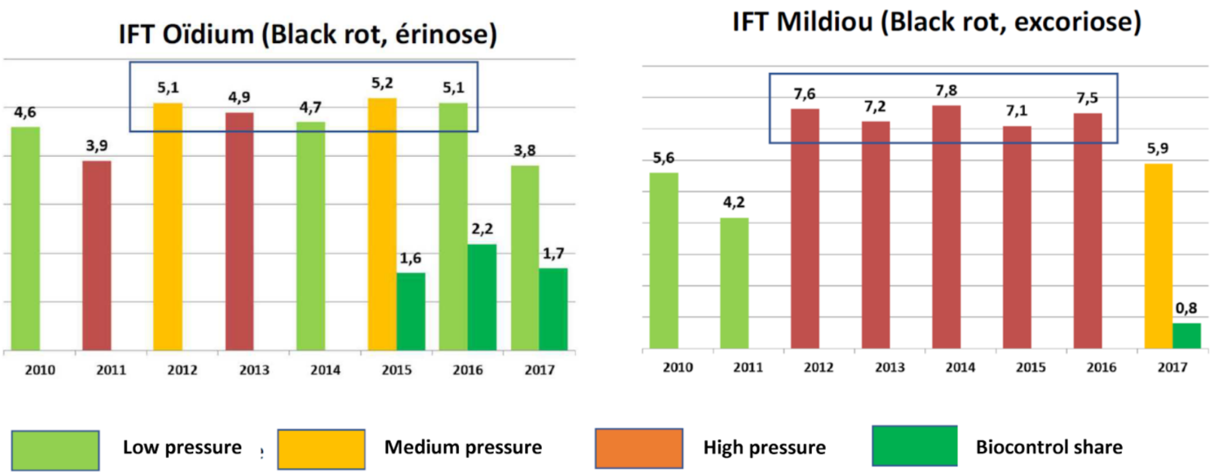


Figure 28: IFT values for the Saint-Emilion/Pomerol pilot site since 2010 (GDON du Libournais)

Between 2010 and 2016, the average number of applications per hectare (IFT) for powdery mildew was 4.8 and the average of downy mildew was 6.7. The IFT average was higher between 2012 and 2016, which were 5 years with high pressure for downy mildew, with an average powdery mildew IFT of 5.0 and an average IFT downy mildew of 7.4 on this pilot site. There was a major spring frost event in April 2017, causing much vineyard damage, so the general IFT recorded during this year was lower than the other years and thus not taken into account in these averages.

Table 13: IFT in 2016 for two representative plots

	Plot 552	Plot 32
IFT mildew/oidium no biocontrol	5.77	15.4
IFT insecticide no biocontrol	2.76	4
IFT herbicide	0	0.24
Total IFT no biocontrol	8.53	19.64
IFT biocontrol oidium	2.94	1.25
IFT biocontrol mildew	0	2.45
Total IFT biocontrol	2.94	3.7
TOTAL IFT	**11.47**	**23.34**

4.2.1.4 Climate change

In the Bordeaux region, climate change can be illustrated by multiple indicators (Figure 29).

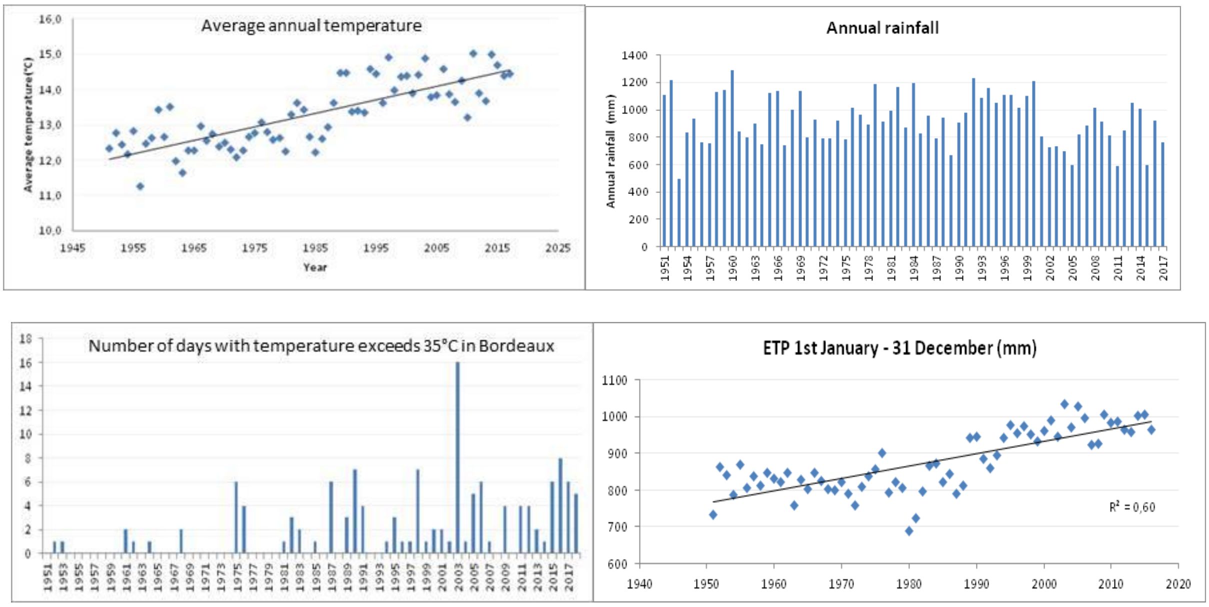


Figure 29: Climate change indicators in Bordeaux (Météo France weather station of Mérignac).

ETP = Potential evapotranspiration (mm)

Data from the meteorological station of Merignac (MétéoFrance Bordeaux), show that the average annual temperature has strongly increased since 1987. In fact, the average annual temperature from 1987 to 2017 is 1.6 °C higher than the average of the annual temperature from 1951 to 1986.

The annual rainfall recorded by the meteorological station of Mérignac has not changed significantly over last decades.

The number of days with an average temperature greater than 35 °C per year has increased on the pilot site. During the 24 years from 1951 to 1974, the Merignac meteorological station never recorded more than 2 days with temperatures greater than 35 °C in one year. Since 2003, the same station has recorded 10 years with more than 2 days with temperatures over 35 °C.

Since 1951, the potential evapotranspiration (ETP) has increased by 200 mm. This increase of ETP is not related to rainfall but is correlated with the increase in temperature (Figure 29).

These climate change indicators have several impacts on grape production: the increase of temperatures and resulting ETP can increase the risk of water deficit in dry areas and modify berry composition and wine typicity. Climate change can also affect the frequency and intensity of grapevine pests and diseases.

4.2.1.5 Soil erosion

Soil erosion is not a common feature of the Saint-Emilion/Pomerol pilot site, as most of the plots have ground cover in the inter-row that reduces erosion. Intensive soil preparation prior to plantation can, however, lead to soil degradation (van Leeuwen et al., 2018).

The surface runoff of precipitation water is the main requirement for soil erosion. To determinate environmental indicators for the two representative plots, we calculated the amount of runoff water using the curve number method (CN = 86 for bare soil, CN = 58 for grassed soil) for the year 2017 as an indicator for the risk of erosion (Table 14).

Table 14: Soil runoff calculation for two representative plots

	Plot 552	**Plot 32**
Inter-row	Alternating	Grass on entire surface
Intervine	Mechanical weeding	Chemical weeding
Rainfall per year in mm	904	904
Runoff per year in mm	83	44

4.2.1.6 Soil acidification

Soil acidification in generally not a problem in the Saint-Emilion/Pomerol pilot site, as the majority of soils are calcareous, thus neutral or basic.

4.2.1.7 Soil compaction

Soils from Saint Emilion/Pomerol pilot site are not prone to soil compaction. Few of the soils are loamy, and the majority of the inter-row soils in the vineyard are covered with grass, limiting soil compaction.

4.2.1.8 Biodiversity

In 1999, Saint-Emilion, Pomerol and six other towns in this grape region were registered as a UNESCO World Heritage site. This registration increases the importance of the viticultural landscape for this region. Several plans were established to limit human impact on the biodiversity of this area.

In this pilot site, the Dordogne River is protected within the *Natura 2000* network, following the 02/01/2008 decree on the creation of protected areas. This area includes the towns of Saint-Emilion, Saint-Sulpice-de-Faleyrens and Vignonet. The objective of the Natura 2000 protection area, by definition, is to create a network of tracts benefitting local flora and fauna. This followed the setup of the *Directive Oiseaux* (1979) for bird protection and *Directive Habitats* (1992) for the conservation and/or restoration of rare or fragile natural habitats for threatened plant and animal species.

In 2009, the Wine Council of Saint-Emilion created the project Landscape and Biodiversity, which included the appellations of Lussac, Puisseguin and Saint-Emilion. The objective is to establish favourable development plans for biodiversity, and the protection of the environment without altering the landscape’s identity.

This study established 11 landscape units, which can be grouped into four categories (Figure 30):

- Vineyard units (5 landscape units, 46 % of the territory);
- Forested units (3 units, 17 %);
- Transition units (2 units, 30%);
- Urban units (7%).

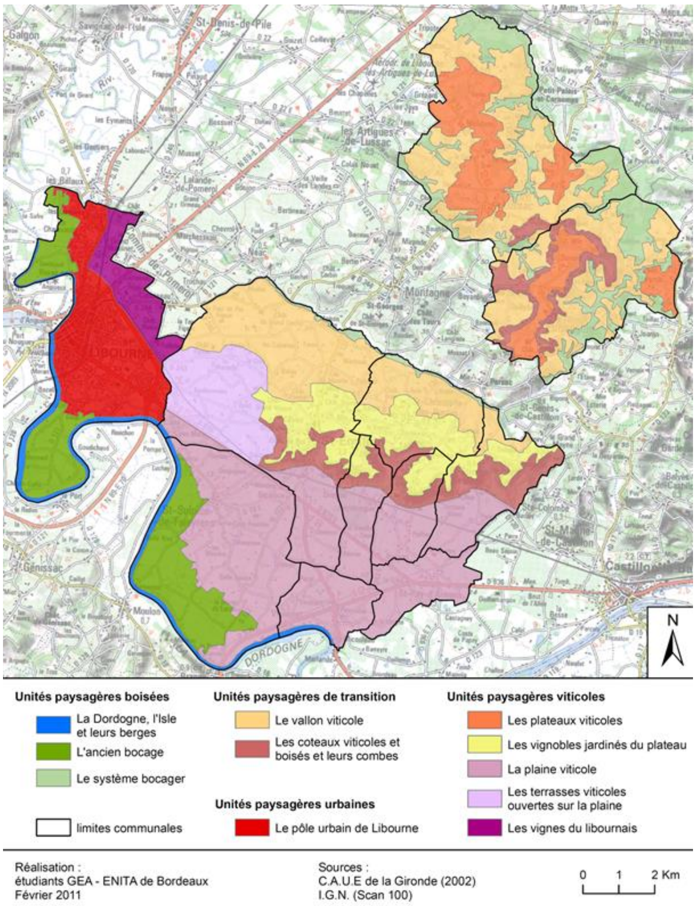


Figure 30: Landscape units in the Saint-Emilion/Pomerol pilot site (ENITAB, 2011)

The results of this study indicate the need to develop ecological connections to improve biodiversity (fauna and flora), with a low visual impact on the open landscape created by the multiple vineyards in this area. The solutions proposed by this schedule are to populate hedgerows, low free vineyard hedges, isolated trees and groves, grass strips and fallow areas with natural vegetation.

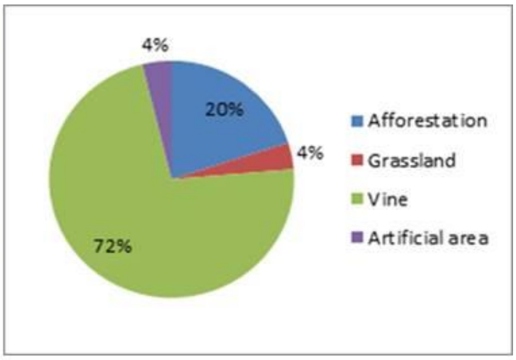
The LIFE+ 2009 BioDiVine project, concerned with managing biodiversity in vineyards through landscape management, was conducted on Saint-Emilion vineyards. During this project, 52 bird species were recorded in 2012 and 44 in 2013. This project encouraged the plantation of 2.8 km of hedgerow, permitted the development of biodiversity on 10 hectares of plots and introduced vegetal cover on 36 ha, with all relevant information disseminated to the grapegrowers.

To measure the environmental indicators for biodiversity, the percentage of natural habitats (grassland and afforestation) around the plots have been calculated (Table 15).

Table 15: % of semi-natural habitats at 300 m around two representative plots

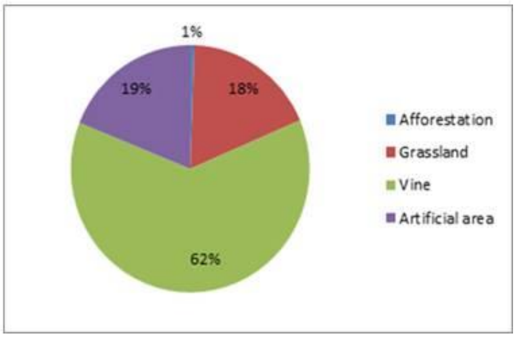
PLOT 32	ha	%
Afforestation	4,89	20,0
Grassland	0,89	3,6
Vine	17,71	72,5
Artificial area	0,94	3,9
TOTAL	24,43	100

% semi-natural habitats : 23,6 %



Plot 552	ha	%
Afforestation	0,1	0,5
Grassland	4,8	18,1
Vine	16,5	62,5
Artificial area	5,0	18,9

% semi-natural habitats : 18,6 %



4.2.1.9 Carbon footprint

The *Conseil Interprofessionnel du Vin de Bordeaux* (CIVB: Bordeaux Wine Council) conducted two studies on the carbon footprint of the Bordeaux wine industry, which included not only viticultural practices but also winemaking, processing and marketing. In 2008, the first study demonstrated that incoming materials, freight and energy (electricity, fuel consumption, etc.) represented 75 % of greenhouse gas emissions (Figure 31).

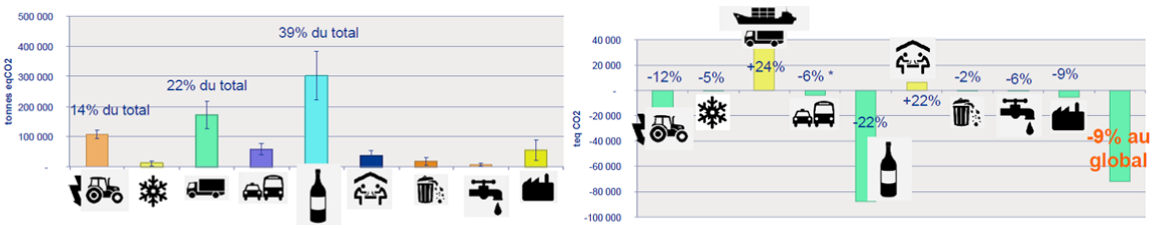


Figure 31: Quantity of greenhouse gas emissions by activity in 2008 (left) and difference of greenhouse gas emissions by activity between 2008 and 2012 (CIVB)

Actions were taken to reduce greenhouse gas emissions prior to the second study in 2012. For example; working groups were set up to reduce the carbon footprint of viticulture material, transport and energy use. This work has also developed research programmes and information bulletins around these topics. The second study (2012) showed a decrease of 9% in the total greenhouse gas emissions by the Bordeaux wine industry (Figure 39). This sector has recorded large greenhouse gas emissions variations, for instance, an increase in freight emissions of 24 % and a decrease in incoming materials of 22 %.

Following this study, the objectives set by the CIVB for 2020 are a 20 % reduction in greenhouse gas emissions, energy consumption and water consumption, and a 20 % increase in sustainable energy use.

The GHG emissions of viticultural activities were calculated for all 15 representative plots in action B2.

4.2.2 The environmental impact of future scenarios

Results presented in this part of the report are a key issue for reflection on the future of viticulture in the Saint-Emilion/Pomerol pilot site. Innovations such as the creation of resistant varieties by breeding, the improvement of machinery or the discovery of new active crop protection products may change the future environmental impact of viticultural practices.

4.2.2.1 Treatment frequency

The environmental impact of different adaptation scenarios was analysed. A comparison of the status quo and the estimated future impacts allows the identification of future environmental risks. The results of the evolution of management strategies using the SEVE model (in part 3 of this report), demonstrate an increase in the number of plant protection treatments in the second period (2080 – 2100). This increase in treatment frequency may impact water quality as well as biodiversity. The increase in GHG emissions generated by sprayers will also affect climate change and the carbon footprint of the Bordeaux vineyard.

4.2.2.2 Water management and erosion

For all the climate change scenarios considered, irrigation will not become essential for grapevine cultivation on this pilot site. Environmental indicators, such as soil erosion or water management will also not be affected.

4.2.2.3 Plant material and grape variety

The results of the SEVE model indicate that whatever the scenarios and periods considered, the use of different grapevine varieties will be necessary. In the short term, the site can adapt by simply changing the mix of local grapevine varieties already included in the appellation specifications. In the longer term, other later grape varieties, native to warmer regions, may become more suitable. These changes are not expected to have strong environmental impacts, unless disease-resistant varieties are introduced. This choice would have an impact on the frequency of plant protection interventions.

4.3 Socio-economic assessment

Socio-economic impacts of climate change were assessed for the 15 representative plots of Saint-Emilion/Pomerol pilot site, based on the viticultural practices used during the 2016 vintage.

These vineyards are outlined below in Table 16. When calculating costs, their varying planting densities had to be taken into account, as this led to a variation in the labour time needed to prune and maintain the vines. Two of the plots were managed to organic standards, and the other plots used conventional production methods. Plots 55 and 552 were managed by the same vinegrower, but one was organic and the other conducted under conventional methods. Three different inter-row vineyard floor management systems were used: bare soil, grass cover, and alternating rows of bare soil and grass cover. Both mechanical and manual harvesting was carried out. Pest and disease management practices also considerably affect the production costs, due to a variation in the number of applications and the type of inputs.

Table 16: Characteristics of the 6 selected plots in the Saint-Emilion/Pomerol pilot site (Alternative = alternating plant cover and bare soil in inter-row)

	ha	Plantation density	Conventional / Organic	Inter rows plant cover surface	Inter vine soil management	Grape harvesting
Plot 1	1,2	5500	Organic	Bare soil	Mechanical weeding	Manual
Plot 9	0,1	6400	Conventional	Entire surface	Chemical weeding	Mechanical
Plot 14	2	5820	Conventional	Alternative	Mechanical weeding	Manual
Plot 15	0,2	6000	Conventional	Alternative	Chemical weeding	Mechanical
Plot 32	1,5	6000	Conventional	Entire surface	Chemical weeding	Mechanical
Plot 55	2,2	6000	Conventional	Alternative	Chemical weeding	Mechanical and Manual
Plot 552	1	6500	Organic	Alternative	Mechanical weeding	Mechanical
Plot 70	1	5800	Conventional	Alternative	Mechanical weeding	Manual
Plot 78	0,3	5900	Conventional	Entire surface	Chemical weeding	Manual
Plot 83	0,53	6000	Conventional	Alternative	Mechanical weeding	Manual
Plot 90	1,5	5500	Conventional	Entire surface	Chemical weeding	Manual
Plot 102	0,7	6500	Conventional	Entire surface	Chemical weeding	Mechanical
Plot 106	2,86	5700	Conventional	Alternative	Mechanical weeding	Mechanical
Plot 232	0,62	6500	Conventional	Entire surface	Mechanical weeding	Manual
Plot 242	0,9	6500	Conventional	Bare soil	Mechanical weeding	Manual

4.3.1 Current practice costs at the plot scale

The references taken into account to determine the costs in this paragraph come from “Référence vigne” (Roby et al, 2008).

4.3.1.1 Total cost by plots

A summary of the number of interventions per operation for each selected plot is shown on Table 17. Numbers of intervention varies from 27 (plot 9) to 62 (plot 1). Average number of practices per year is 41.

Table 17: Number of viticultural interventions per operation for each plot

	Plot 9	Plot 102	Plot 14	Plot 90	Plot 106	Plot 83	Plot 78	Plot 232	Plot 242	Plot 1	Plot 15	Plot 32	Plot 55	Plot 70	Plot 552
Pruning	3	3	3	3	3	3	3	4	4	3	3	3	3	3	3
Soil management	6	3	9	6	11	11	9	12	10	11	9	5	9	10	14
Vine management	0	0	0	1	2	0	1	2	2	1	1	3	1	1	1
Trellising management	1	1	1	0	1	1	1	1	1	1	1	0	0	0	1
Canopy management	7	11	10	13	10	10	12	11	11	5	12	10	10	9	11
Fertilizer application	0	0	0	0	0	0	2	2	2	13	1	0	2	5	1
Fungicide application	9	16	12	14	11	11	10	12	12	27	11	17	13	13	16
Harvest	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1
TOTAL	**27**	**35**	**36**	**39**	**39**	**37**	**39**	**44**	**42**	**62**	**39**	**39**	**40**	**42**	**48**

Figure 32 compares the total estimated annual production cost per hectare for each vineyard. The average cost is 7,804 €/ha, with a variability of 3,680 €/ha between the minimum cost (6,262 €/ha) and the maximum cost (9,943 €/ha).

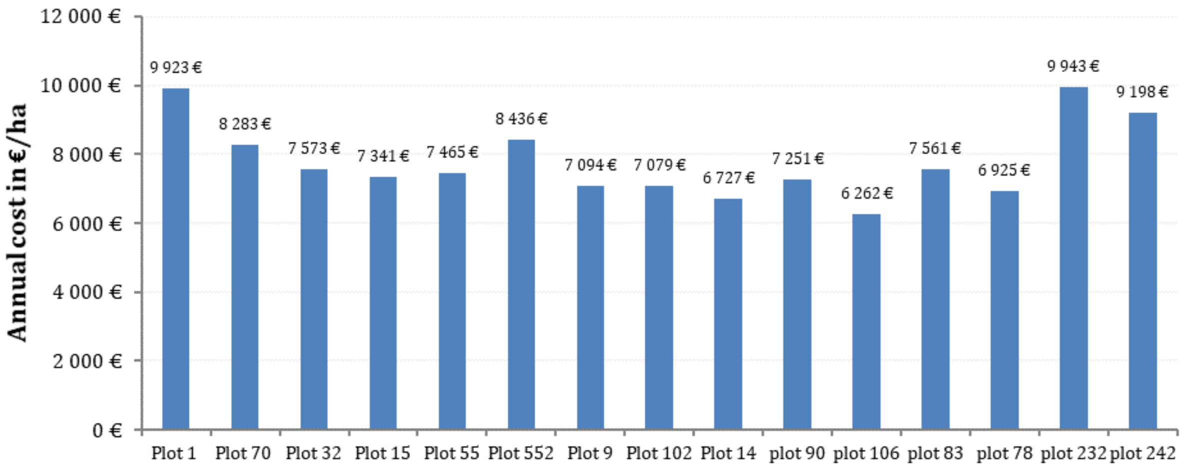


Figure 32: Annual maintenance cost estimation per hectare for selected plots on the Saint-Emilion/ Pomerol pilot site

4.3.1.2 Cost of individual operations

4.3.1.2.1 Plot comparison

More details on the cost estimation for each viticultural operation on the selected plots are provided in Figure 33. Canopy management and pruning are the main expenses for all the plots, except for plot 1, which seems to spend more money on pesticide and fertiliser applications.

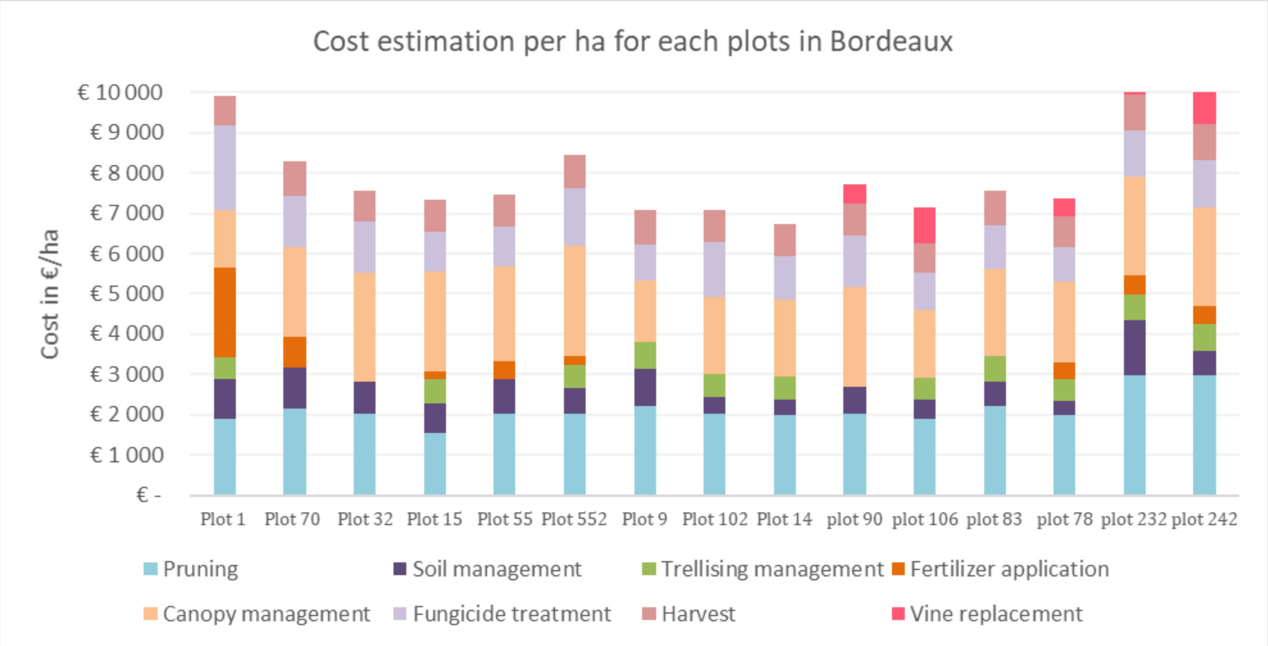


Figure 33: Cost estimation per ha split up by sub-viticultural operations for each plot in the Saint-Emilion/Pomerol pilot site

Plot 1, which is managed to Organic standards, required a greater number of interventions (particularly pesticide applications) throughout the year. The annual cost for Plot 1 is lower for the canopy management because the vinegrower does not trim during the season. The costs for the plot 552 (also managed to Organic standards) is higher than plot 55 (same estate) because more interventions are required for canopy management and plant protection.

Pruning costs is around 2,000 euros/ha for each plots, which represents 15% to 35% of the annual cost. Pruning is more expensive for plots 232 and 242 because they have one more intervention than the other plots, which is pre-pruning. The pruning cost is also higher in plots with higher planting density and where the shoots are shredded.

Canopy management represents the most expensive practice with pruning during the year. In average, canopy management represents 15% to 35% of the annual cost, as pruning.

Fungicide treatment is also one of the most expensive practices. Differences are mostly due to the number of interventions.

4.3.1.2.2 Comparison of viticultural operations

Figure 34 illustrates that canopy management and winter pruning are the most expensive viticultural practices, with an average spend of 2,167 € per hectare for canopy management, and 2,132 € per hectare for winter pruning.

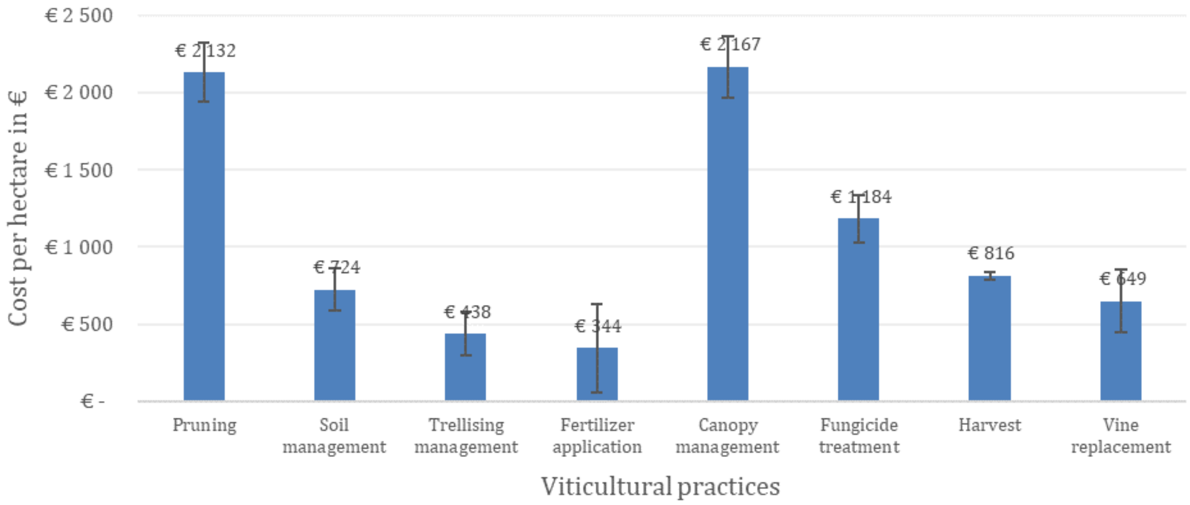


Figure 34: Average cost estimation per hectare for each viticultural practice applied on the plots selected in the Saint-Emilion/Pomerol demonstration pilot sites.

However, a significant standard deviation can be noted for canopy management costs. This can be explained by the broad range of operations included in canopy management, such as dis-budding, leaf removal, thinning and trimming. The number of operations, the material and the number of workers will significantly influence this result. The standard deviation for fungicide treatments is affected mostly by the engine power of the sprayer, whereas the pruning cost is affected by the number of workers and the duration of this practice. The average soil management cost is 724 €, with a low standard deviation.

Trellising and the fertiliser application costs are not easy to analyse, as not all the plots are carrying theses viticultural operations.

4.3.2 The socio-economic impact of future scenarios

According to the results generated in Action B1, the main viticultural operation that is going to change in the future is plant protection. A significant increase of these treatments is predicted by SEVE model during the period 2081-2100 for all plots. The evolution of fungicide treatment is very variable between plots, which not allow us to calculate future cost with precision for this scenario. Predicted cost for pest and disease management for each plot over the years 2080-2100 will be higher compared to the year 2016. This increase can be significant for winegrowers because fungicide treatment is the third most expensive practice during a year.

However, socio-economic issues will be related to the increase of frost risk during the period 2081-2100, or more frequency summer drought, placing much pressure on winegrowers to produce sufficient volumes of wine to ensure the viability of the company. Future innovations are therefore required in soil management and frost management, but we can't estimate the cost.

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.

The current GHG emission level of the most emitting plot (3000 kg eq CO_2/ha/year) was found to be three times higher than that of the least emitting plot (1180 kg eq CO_2/ha/year). Plant protection and soil maintenance were identified as the most emitting (direct and indirect emissions) operations during the 2016 campaign. The variation in GHG emissions between operations is mainly caused by the engine power of vineyard tools and the frequency of interventions. Harvest, trellis management and vine maintenance are the most emitting practices, due to the use of high engine powered vehicles.

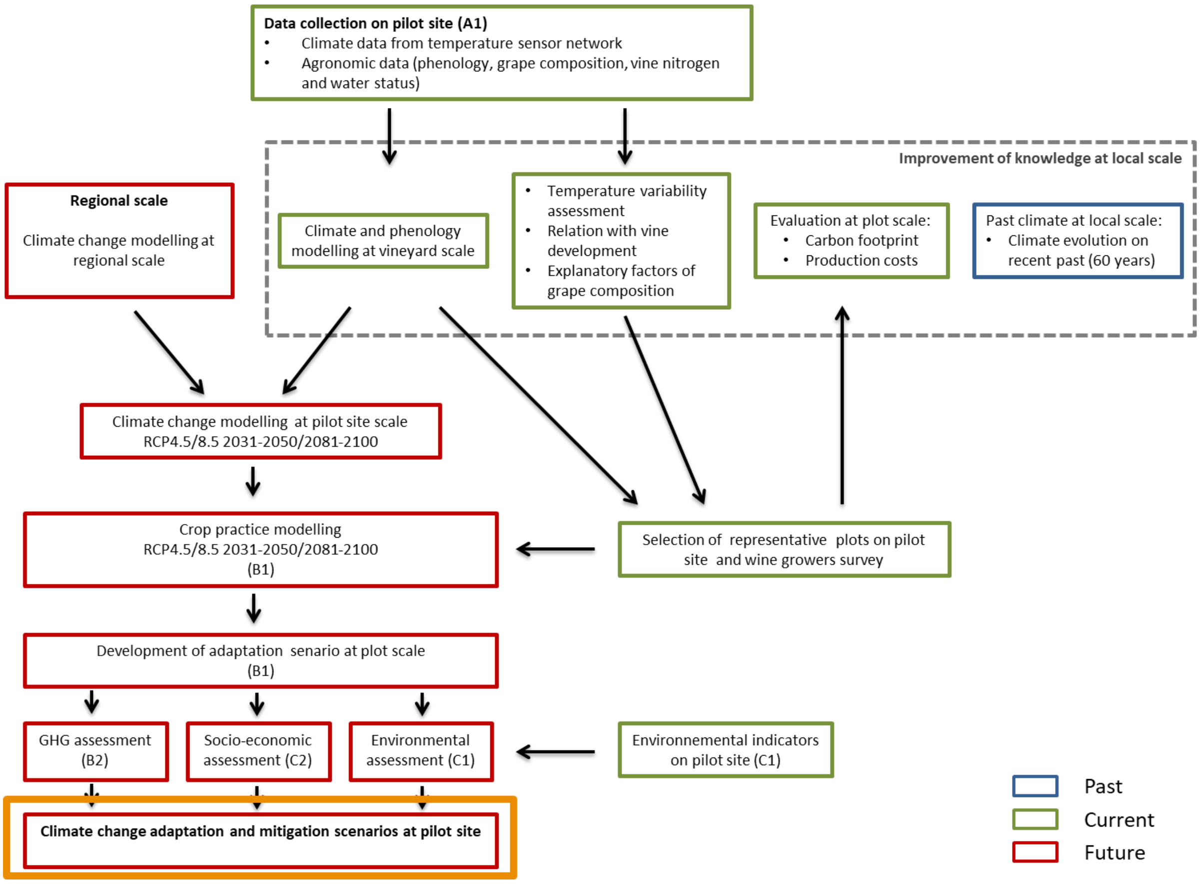
The SEVE model produced adaptation scenarios for three plots, which differed from current practice due to the number of pesticide applications: they remain stable or increase slightly for the period 2031-2050, then increase significantly for the period 2081-2100. The increases of GHG emissions from pesticide applications can have a significant environmental impact due to the high level of GHG emissions induced by fungicide treatment during a year.

Current environmental indicators were also defined to assess the environmental impact of adaptation scenarios. The general description of the most relevant environmental indicators allowed to define issues. The two main bodies of water in the area, the Barbanne and Dordogne Rivers, are classified as having poor ecological status, whereas the groundwater is classified with good chemical status. The mean number of pesticide applications between 2010 and 2016 were calculated, and resulted in a figure of 4.8 for powdery mildew and 6.7 for downy mildew. Biodiversity in the trial area was protected and managed by several actions over the last 20 years, in particular by the LIFE+ 2009 BioDiVine Project, which encouraged the development of semi-natural habitats. To measure environmental indicators for biodiversity, the percentage of natural habitats around the trial plots were calculated.

Water quality and the number of pesticide applications may be affected by future adaptation scenarios, particularly by the increase in treatment frequency in the 2080-2100 period. The increase in sprayer utilisation may also increase GHG emissions and affect the carbon footprint of the trial area.

Regarding the socio-economic impact of climate change on viticultural operations, the most expensive operations for the vinegrowers of the Saint-Emilion/Pomerol pilot site are canopy management (average of 2,167€ per ha) and winter pruning (average of 2,132€ per ha), followed by pesticide application (1,184 €). The number of interventions, the machinery used and the number of vineyard workers in the significantly affect the cost. In the near future (2031-2050) the number of pesticide applications should not intensify, but, in the 2081-2100 scenario, it is estimated that they will increase, which could have a significant impact on production cost.

PART 5: CONCLUSION



The overall results obtained on the Saint-Emilion/Pomerol 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

1951-1980 / 1981-2010

Tmean growing season : **+ 1,5°C**

Huglin Index : **+ 273 degree-days**

Current / pilot site scale

Climate

High temperature variability :

- Daily amplitude :
  3.9°C for minimum T°C (until 10°C)
  3.2°C for maximum T°C
- Variability of Huglin index : **284 degree-days**

Strong effect of environmental factors on temperature distribution

- Tn :
  with **elevation**, **slope** and weak effect of **exposure**
  from **west to east** and weak effect of **south to north**
- Tx :
  with **elevation** and weak effect of **slope**
- Canopy WI :
  with **elevation, slope** and weak effect of **exposure**
  from **west to east** and weak effect of from **south to north**

Vine development

High intra-annual variability of phenology and maturity

Budbreak

19 days

Flowering

9 days

Veraison

13 days

Maturity (200g/l of sugar)

25 days

Grape variety :

Merlot / Cabernet franc / Cabernet-Sauvignon / Petit Verdot / Carmenère

Maturity (S/TA)

Strong effect of Tn, Tx, water deficit and weak effect of berry weight and YAN

Current / plot scale

GHG emissions

Average

1864 kg eq CO_2/ha/year

Variation

1180 to 3000 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

Production cost average

7804 €

Variation

6262 € to 9943 €

Most expensive practices during one campaign

Canopy management (2,167 €/ha in average)

Pruning (2,132 €/ha in average)

Major factors of variation

Number of practices

Material

Number of workers

Environmental indicators

Water quality

Poor ecological status

(Barbane and Dordogne rivers)

Use of treatments

Treatment frequency index (2010 to 2016)

4.8 Powdery mildew

6.7 Downy mildew

Biodiversity :

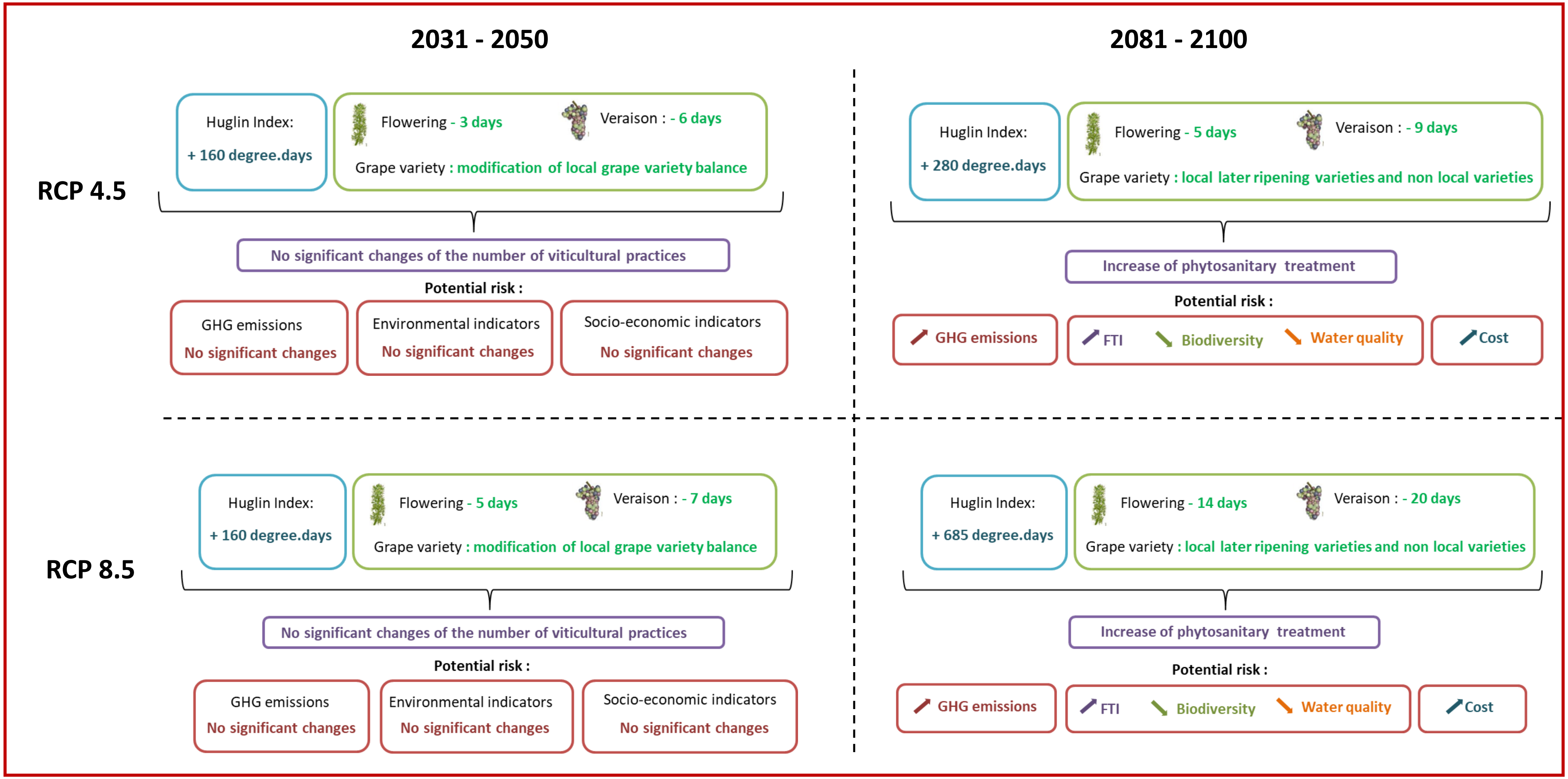
Landscape and biodiversity project:

20% semi-natural habitats

LIFE+ 2009 BioDiVine project :

44 bird species (2013)

Future / pilot site and plot scale



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