



Adaptation of cultural practices to climate change

Results synthesis



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FOREWORD

Across the earth, there is growing evidence that a global climate change is taking place. Observed regional changes include rising temperatures and shifts in rainfall patterns and extreme weather events. Over the next century, climate changes are expected to continue and have important consequences on viticulture. They 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 includes adapting to these potential impacts, as well as reducing greenhouse gas emissions related to their activities. In response to these challenges, recognising the need to assess climate and its impact on viticulture at the vineyard scale, the LIFE-ADVICLIM project was focused on the study of climate change adaptation and mitigation scenarios for a

range of vineyards which represent the climatic diversity of European wine regions.

The use of observation, modeling and reporting tools seeks to inform and assist winegrowers on climate change impacts, on rational adaptation scenarios and on greenhouse gas emissions related to their practices at the scale of their vineyard plots.

These technologies have been implemented and tested on demonstration sites in five European vineyards regions: Cotnari, Rheingau, Bordeaux, Sussex and Val de Loire, thanks to funding from the European Life program.

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

About this manual

This manual focus on simulation of viticultural management practices and decision-making in response to climate change at the vineyard level. It has been developed on the basis of scientific research and many field observations. However, this document is not intended to provide management planning, but meant to generate potential trajectories of adaptation according to different scenarios of climate change.

Simulation outputs illustrate some potential agronomic strategies among a set of potential strategies. However, even if we used bias-corrected climate data, there is uncertainty in the data included in SEVE and the model at different scales propagates this uncertainty. Therefore, the results must be interpreted with caution given this uncertainty.

1. Overall objective

The B1 action was fitted to the development of tools that allow wine growers to better define actual and future agro-climatic potentials, which will ensure in the context of climate change, quality and sustainable wine production over time.

Since the beginning of the ADVICLIM program, the work of the action B1 has been focused on to the formalization and implementation of a multi-agents model to address the simulation of vine phenology and agronomic activities at plot scales. In this context, a specific model named SEVE (Simulating Environmental impacts on Viticultural Ecosystems) has been designed to describe viticultural practices with responsive agents constrained by exogenous variables (biophysical, socioeconomic and regulatory constraints).



Figure 1 Pilot site experimented in the ADVICLIM program

What is multi-agent modelling?

It is a computerized framework for describing and simulating complex systems, which are characterised by interactive autonomous agents. In this context, agents are computing systems that occupy a complex and dynamic environment, sense and act autonomously in this environment, and by doing so, realize a set of goals or tasks for which they were designed.

Based on GAMA simulation framework (<https://gama-platform.github.io/>) SEVE (Simulating Environmental impacts on Viticultural Ecosystems) model has been designed to describe viticultural practices with responsive agents constrained by exogenous variables (biophysical, socio-economic and regulatory constraints). Each activity is represented by an autonomous agent able to react and adapt its reaction to the variability of environmental constraints.

The baseline of SEVE model has three main class of Agents (figure 2):

- the "Supervisor" Agent plays a overseeing role in the model. It sets the specifications of the various wine designations and imposes specific grape and wine production regulations. It is directly related to the "Winegrowers" and "Plot" Agents, who provide synthetic information about phenology (i.e. bioclimatic indices values) and agronomic action (i.e. number of fungicide treatment). According to this information, the "Supervisor" agent may modify production policies and regulations;

- "Winegrower" Agents aim to grow grapes and produce wine that meets precise specifications according to their end-product goals. This action involves growing the grapevine in optimal conditions given the agronomic specificities of the wine grower's plots;

- "Plot" Agents are grape production entities. They generally represent a vineyard plot or an entity deemed homogeneous in terms of agronomic features (definition based on local terroir units; Bodin and Morlat., 2006). The role of these agents is to reproduce grapevine growth and grape ripening dynamics, according to spatial and temporal environmental variations.

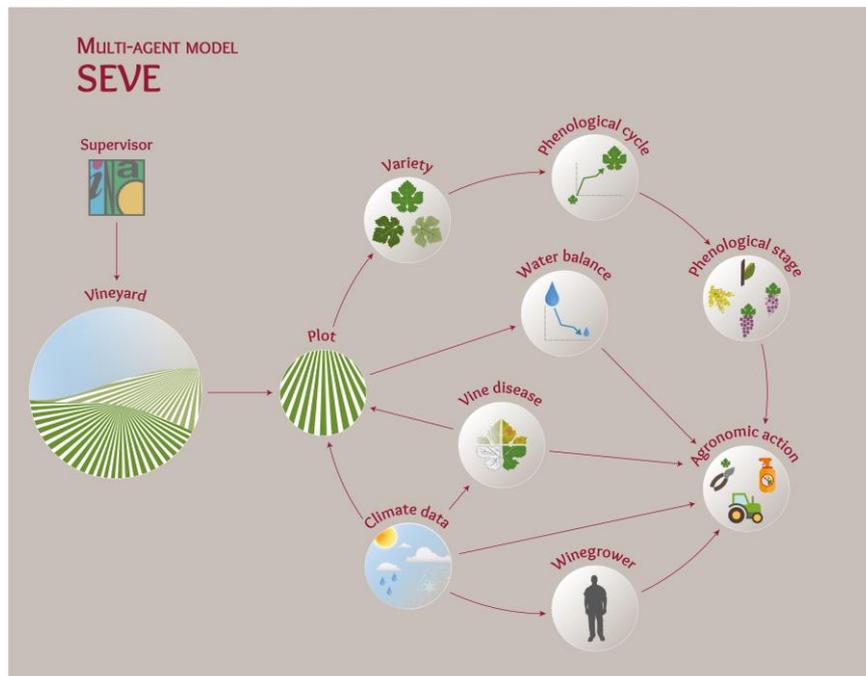


Figure1: simplified modeling sequence of SEVE model

These three main classes are complemented by specific agents. The "Winegrowers" agents have "Winegrowing workers" and "Tractors" agents which enable them to implement agronomic actions. The "Plot" agents are associated with a "Pathogen" agent that simulates the dynamics of diseases such as mildew depending on climatic conditions. Finally, "Sensor" agents provide climate information (meteorological data, bioclimatic indices) useful to "Plot", "Winegrower" and "Supervisor" agents.

According to biophysical properties of plots (topography, soils type, water reserve...) and climate condition SEVE model provide a general framework to simulates vine's phenological cycle and agronomic action. In return, each agent is endowed with responsive capacities expressed through behaviour that changes according to environmental evolution.

Six pilot site with contrasted vineyards configuration have been integrated in the same instance of SEVE model. There is therefore a single model coupled to a database containing a knowledge base for each of the pilot sites. This database centralizes all the knowledge available for the pilot sites around four themes (table 1):

Biophysical data	Climate data	Vine data	Winegrower
<ul style="list-style-type: none"> • Soil nature and type • Maximum soil water holding capacity • Topography (digital elevation model) • Slope • Geographical position and boundaries of vineyard plots 	<ul style="list-style-type: none"> • From weather stations (rainfall, humidity, temperature, wind speed, potential evapotranspiration) • From data-loggers (temperature) • From global climate model (CORDEX data at regional scale, same data as weather stations) • From statistical model (temperature simulated at local scale) 	<ul style="list-style-type: none"> • Vine variety and rootstock • Training system • Planting density • Row orientation • Vine age • Dates of phenological stages for several years according to their climate profile 	<ul style="list-style-type: none"> • Working periods • Agronomic practices • Techniques and machinery involved • Favourable and unfavourables climatic variables

Table 1: Main themes of SEVE model database



Part 1 Bioclimatics indices and phenological cycle

The first objective of this work is to simulate the evolution of the phenological cycle of the vine regarding different scenarios of climate change. In order to take into account, the local effects of climate change, climate data are integrated into the model from different data sources.

For historical period, data about temperature, rainfall, potential evapotranspiration, wind speed and direction are provided by a weather station located close to the vineyards. Temperature data are also provided by sensors installed in the plots according to the pilot site characteristics (slope, exposition, distance to a river...). The objective is to have a network that reflects local climate characteristics. These sensors recorded daily minimum and maximum temperatures from different period (the longest covers the period from 2012 to present).

For future period, data are integrated at regional scale from downscaled climate models output and at local scale from statistical model based on vector machine learning (figure 2). This approach allows the effects of topography and temperature to be calculated and provides data on their spatial distribution at high resolution (100 metres). Climate data are assigned to a plot based on its geographical location (the shortest distance between plot and closest cell centroids). They are used to calculate all relevant bioclimatic indices to simulate vine growth.

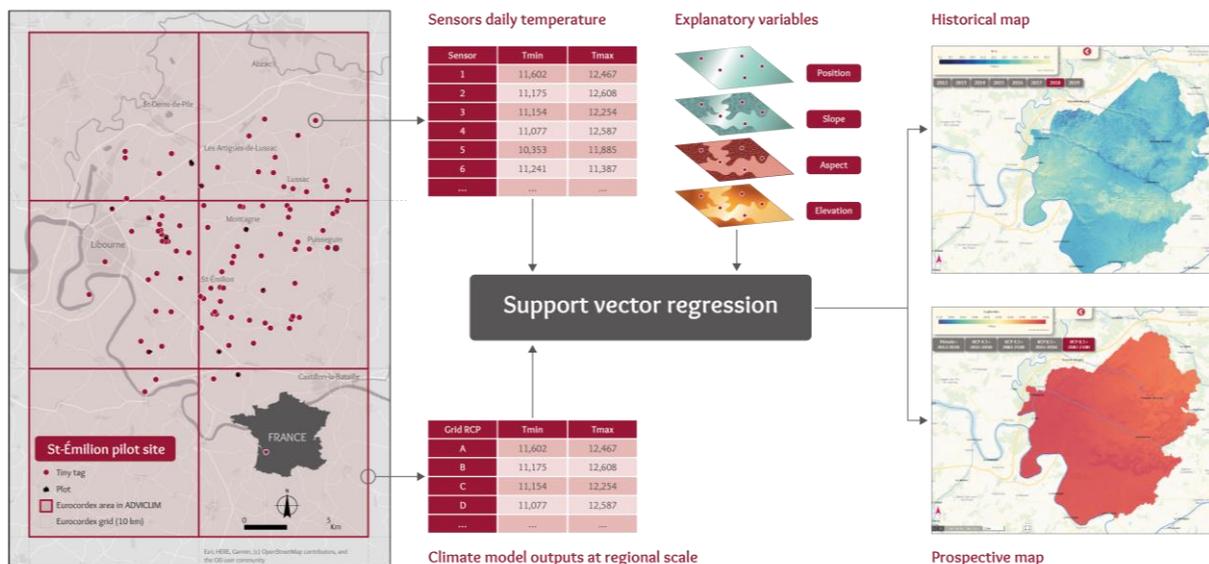


Figure 2: Downscaled approach used to provide temperature data at local scale

In SEVE model, the "Plot" agent has many attributes related to the characteristics of the production plots (soil water reserves, slope index, soil specificity, ...). This agent following phenological stages during its growth cycle and reacts to climatic variability, and other disturbances (e.g. fungal diseases). The transition from one stage to another is calculated from different bioclimatic indices

Looking at the pilot sites as a whole, there has been a significant increase in the value of bioclimatic indices on a European scale. If we consider Huglin Index this evolution is more or less significant depending on the site and the selected climate scenario (figure 3).

Bioclimatic indices

Bioclimatic indices are a useful zoning tool, defining a region's ability to produce grapes, varietal suitability, etc. The two main indices used in viticulture are the Winkler and Huglin Indices. The former refers to the concept of growing degree-days, which is calculated as the sum of daily mean temperatures above 10°C for the period of April to October in the Northern Hemisphere. The base temperature of 10°C refers to the minimum temperature necessary for grapevine physiological activity. The interest in using the Winkler Index is that the cumulated heat is strongly correlated with grapevine phenology. The Huglin Index differs, as it is the sum of the mean and maximum temperature above 10°C from April to September in the Northern Hemisphere. It gives greater weight to daytime temperatures, when most vine development takes place and is therefore strongly correlated with berry composition at harvest.

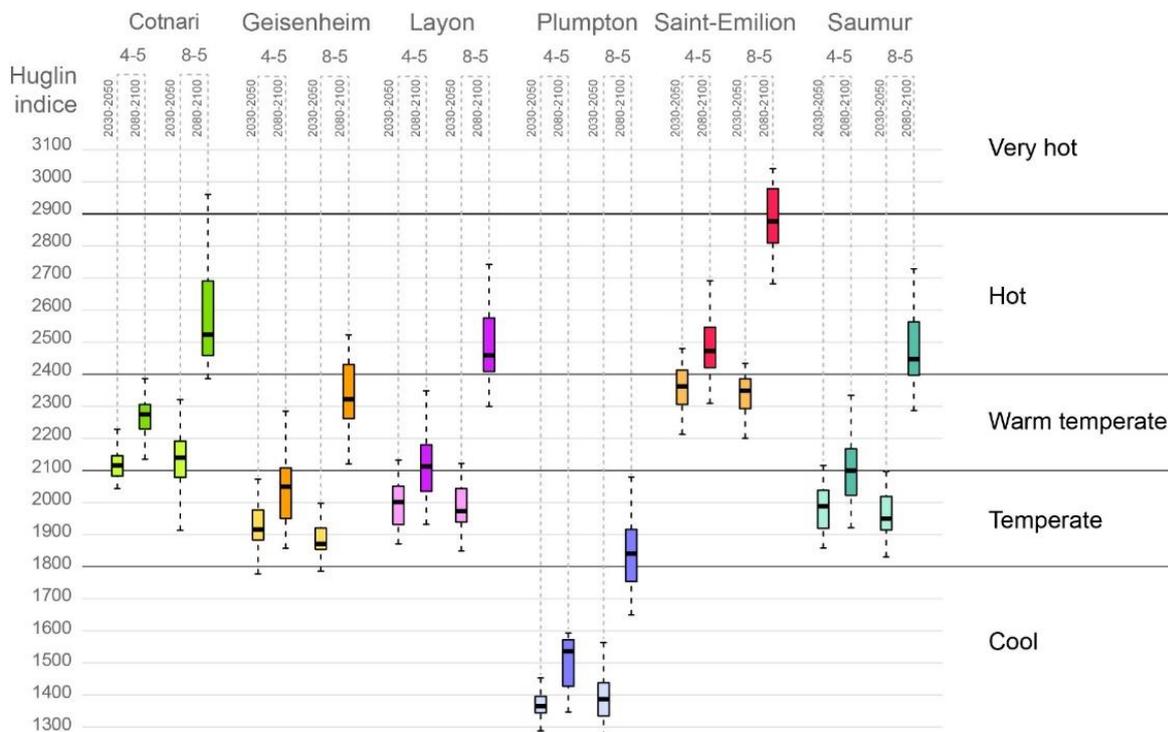


Figure 3: Evolution of the value of the Huglin Index in the different pilot sites according to two climate change scenarios (RCP 4.5 and RCP 8.5)

This increase leads to a change in climate class for several vineyards. For the most pessimistic scenario, this change affects significantly some vineyards like Cotnari or Saint Emilion which reach in some year's extreme thresholds for the cultivation of the vine. On a local scale this increase is moderate or amplified depending on local conditions (altitude, slope and exposure of the plots). Depending on the site, differences of 200 to 400 degree-days can be observed between the coldest and the warmest plots (figure 4).

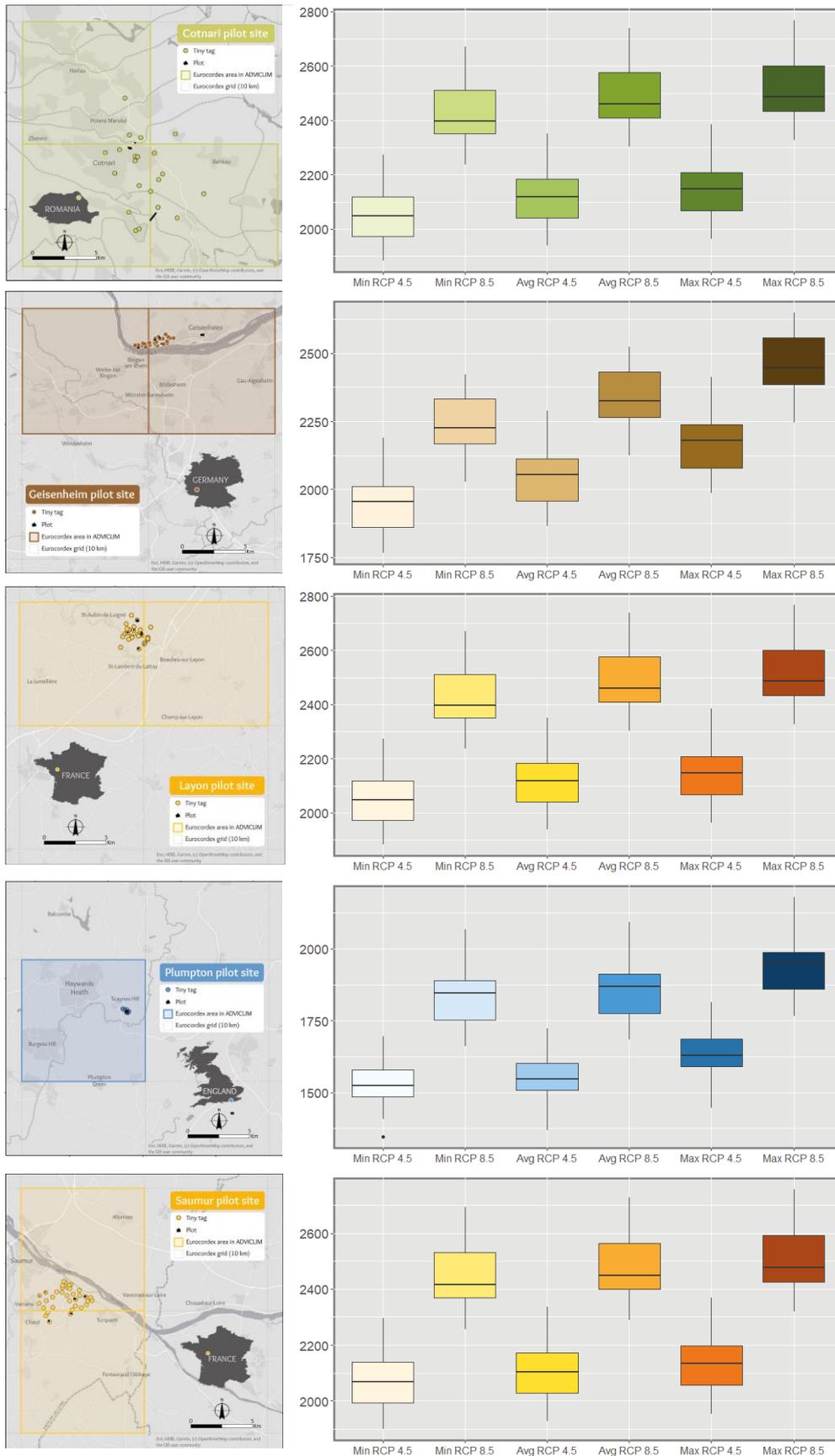


Figure 4: Comparison of Huglin index values between cold, intermediate and warm plots on some pilot site during the period 2080-2100

The increase in cumulative degree days is more moderate in the medium term. A comparison of the periods 2030-2050 and 2080-2100 at the Saint-Emilion site illustrates the acceleration of the increase in the Huglin index over the longer term (figure 4).

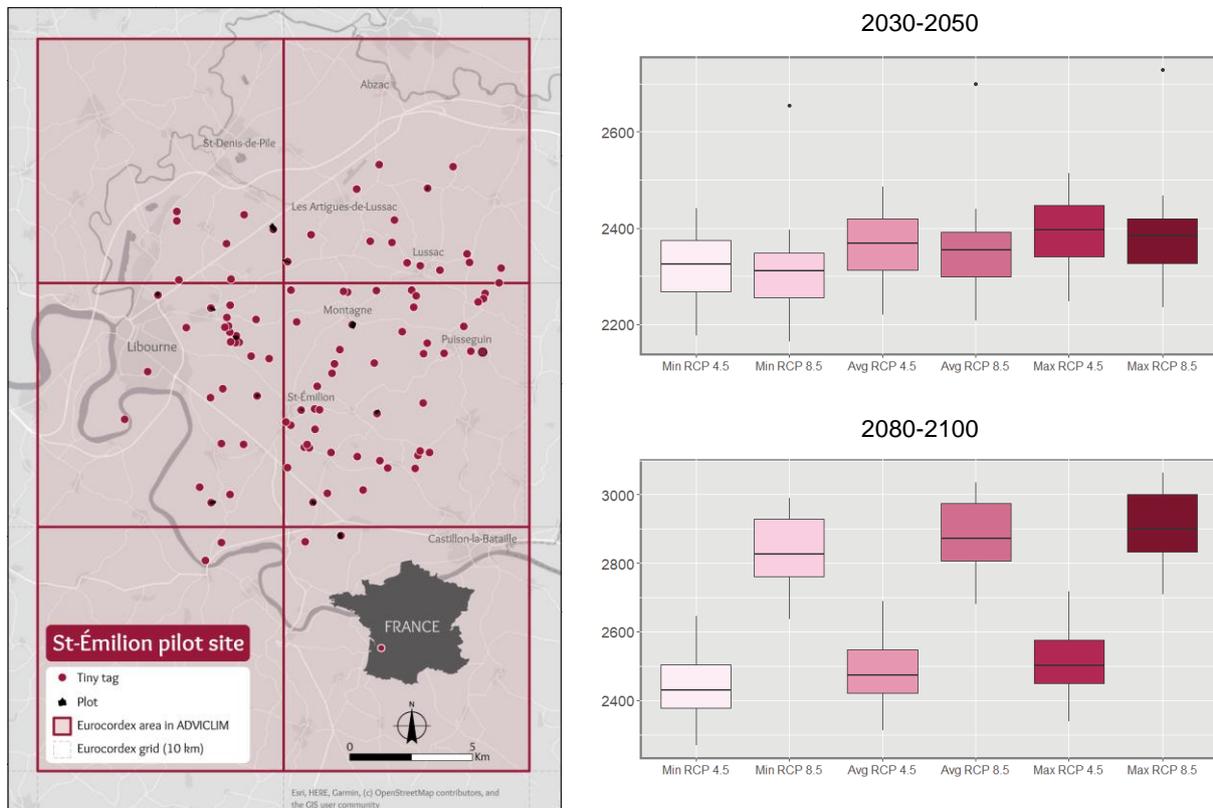


Figure 5: Comparison of Huglin index values between cold, intermediate and warm plots in Saint-Emilion pilot site during the period 2030-2050 and 2080-2100

The evolution of temperatures affects the phenological cycle of the vine and leads to an advance in the phenological stages and an earlier reaching of technical maturity. The SEVE model uses the Baggiolini classification (Baggiolini M., 1952¹) in order to represent the key vine phenological stages (Figure 5).

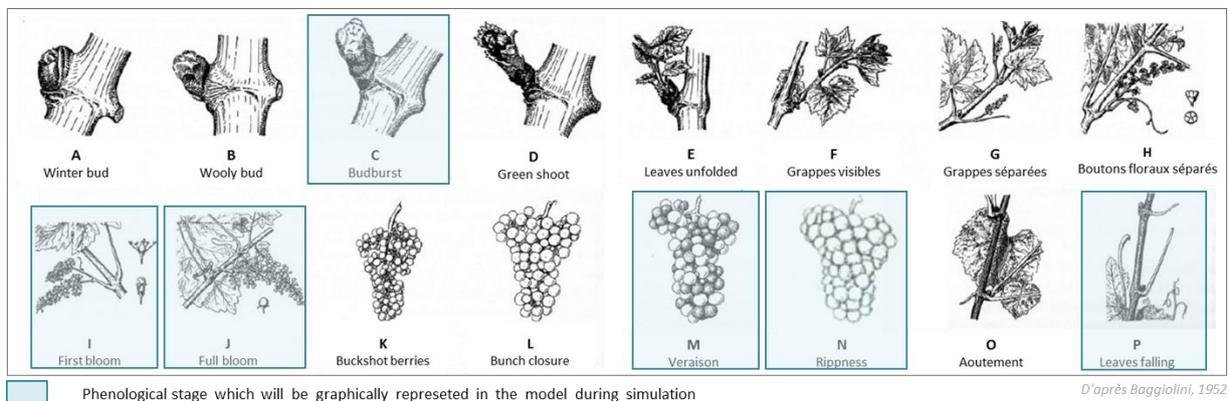


Figure 6: Baggiolini classification of phenological stages

¹ Baggiolini M. (1952). Les stades repères dans le développement annuel de la vigne et leur utilisation pratique. *Revue romande d'Agriculture et d'Arboriculture* 8 (1), 4-6.

Using different bioclimatic indices threshold, SEVE model provides an estimated date of key phenological stages for each simulated agronomic year. The simulation sequence highlights the temporal distribution of the different stages during vegetative cycle (figure 7).

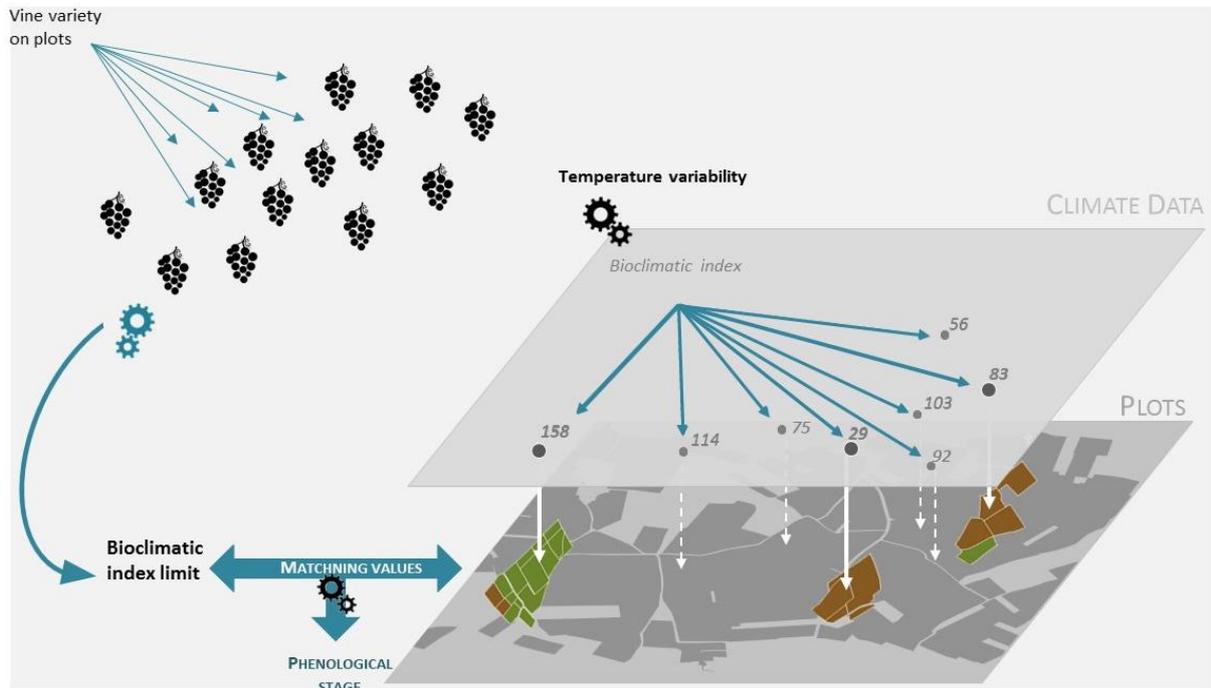


Figure 7: Modelling sequence of phenological cycle in SEVE model

If we focus on budburst, flowering, veraison and maturity stages, early growth is highlighted on all pilot sites (table 2).

Pilot site	Variety	Bud burst	Flowering	Veraison	Maturity	Period	scenario
Cotnari	Feteasca alba	-4	-2	-3	-5	2030-2050	4_5
Cotnari	Feteasca alba	-5	-7	-6	-9	2030-2050	8_5
Cotnari	Feteasca alba	-8	-10	-9	-12	2080-2100	4_5
Cotnari	Feteasca alba	-19	-18	-21	-27	2080-2100	8_5
Geisenheim	Riesling	-2	-3	-3	-5	2030-2050	4_5
Geisenheim	Riesling	-6	-6	-7	-11	2030-2050	8_5
Geisenheim	Riesling	-10	-7	-7	-11	2080-2100	4_5
Geisenheim	Riesling	-25	-16	-21	-31	2080-2100	8_5
Layon	Chenin	-7	-4	-3	-5	2030-2050	4_5
Layon	Chenin	-12	-7	-5	-8	2030-2050	8_5
Layon	Chenin	-17	-7	-7	-9	2080-2100	4_5
Layon	Chenin	-51	-16	-21	-27	2080-2100	8_5
Plumpton	Bacchus	2	-5	-4	-6	2030-2050	4_5
Plumpton	Bacchus	-7	-7	-7	-8	2030-2050	8_5
Plumpton	Bacchus	-9	-9	-10	-13	2080-2100	4_5
Plumpton	Bacchus	-33	-26	-23	-30	2080-2100	8_5
Saint-Emilion	Merlot	-8	-2	-4	-5	2030-2050	4_5
Saint-Emilion	Merlot	-14	-5	-5	-7	2030-2050	8_5
Saint-Emilion	Merlot	-19	-5	-7	-9	2080-2100	4_5
Saint-Emilion	Merlot	-46	-13	-19	-24	2080-2100	8_5
Saumur	Cabernet franc	-7	-5	-4	-7	2030-2050	4_5
Saumur	Cabernet franc	-11	-7	-5	-9	2030-2050	8_5
Saumur	Cabernet franc	-17	-9	-8	-12	2080-2100	4_5
Saumur	Cabernet franc	-39	-17	-21	-28	2080-2100	8_5

Table 2: Advancement of key phenological stages between the historical period and the periods 2030-2050 and 2080-2100 under two climate change scenarios (RCP 4.5 and RCP 8.5). Results generated by the SEVE model are expressed as a number of days the median dates of the historical and future periods are lagged.

The emblematic grape varieties of the pilot sites are all concerned by increased precocity in the future. The simulation results show a more important shift towards the end of the century, especially for scenario 8.5. Technical maturity occurs on average 1 month before the current harvest date on most of the ADVICLIM pilot sites.

This phenological cycle shortening can have an impact on the exposure to frost risk and also on the agronomic itineraries (agronomic practices type, number and calendar).



Agronomic practices

Climate variability affects agronomic practices, i.e. their timing and frequency depending on the conditions of each growing season.

- In hot and dry climate contexts, shallow soil tillage activities are favoured to reduce the grapevine water stress and allow a more optimal soil water availability.
- In normal to wet years, inter-cropping management practices are used to manage grapevine vigour, increase soil tractability and reduce erosion risks.
- For specific practices such as the use of pesticides, they are less correlated to the global climatic profile of the growing season as they depended more on daily temperatures and rainfall amounts, which are highly variable over time.

In SEVE model, winegrower agents are created from three production profiles: conventional (traditional viticulture), integrated (limitation of pesticides, fertilizers and weeding) and organic (strong limitation of pesticides, mechanical weeding...). The results of surveys conducted during the AVICLIM project are used to define potential practice schedules for each production profiles. The main practice constraints are also integrated into the model. Climate data are used to calculate the available days for each agronomic action. According to these data, its production profile, vine phenological cycle and agro-climatic characteristics (soil type, slope, aspect, water balance ...), each wine grower agent performs specific agronomic actions (Figure 8).

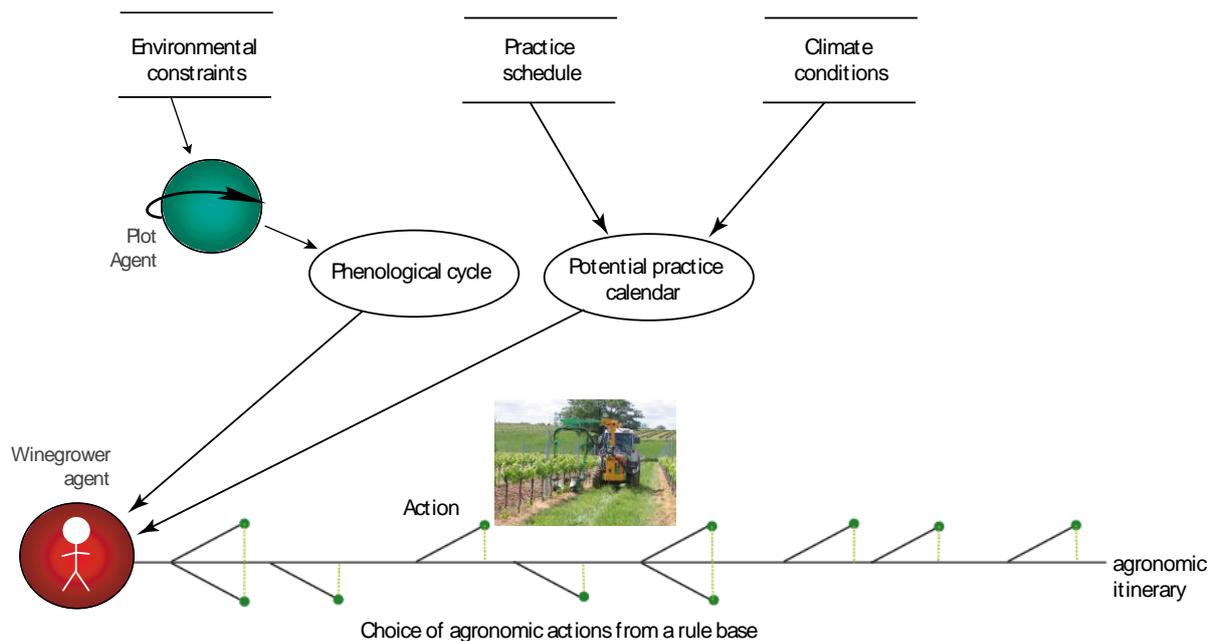


Figure 8: Constraints and processes leading to winegrower's decision making

The more general practices such as pruning or trimming only varied in timing depending the grapevine phenology, but not significantly in frequency. Short term adaptation responses to climate constraints (soil tillage, weed maintenance, fungicide treatment..) are much more variable depending on the climatic profile of the year. Finally, longer-term adaptations depend on the sequence of climate change, which can lead to immediate or planned adaptations. Understanding the human dimension of decision making is extremely important in this context, as each winegrower will respond differently to changing environmental conditions.

Thanks to the surveys carried out on each pilot site, constraints and thresholds could be determined in order to establish decision rules according to local constraints and winegrowers' production strategies. These informations are used by SEVE model to build decision trees (figure 9).

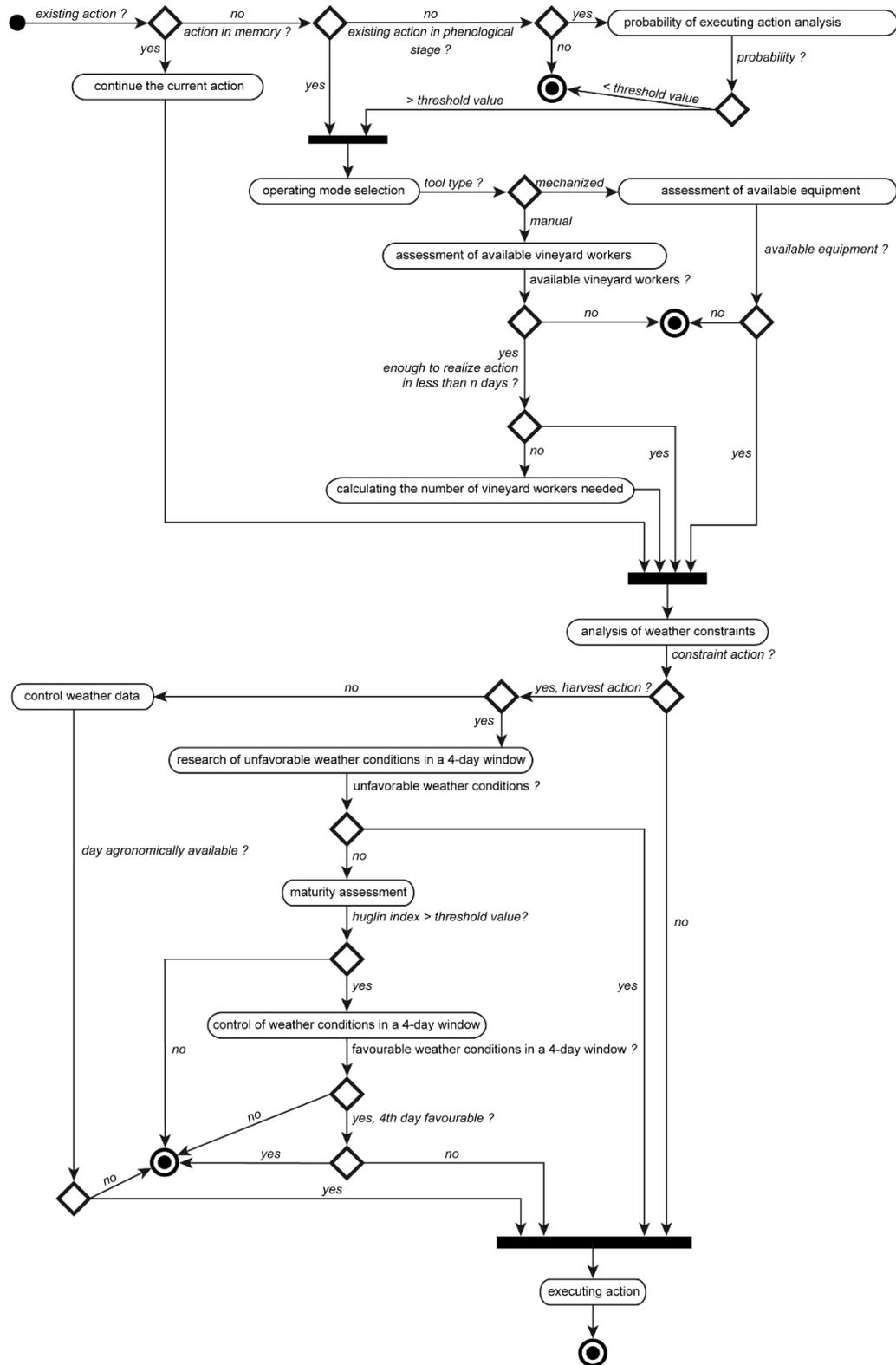


Figure 9: Decision making process carried out by winegrower agents

This decision-making process is used to launch, postpone or anticipate one or several agronomic actions. Consequently, an agronomic itinerary can be calculated for each year. The results are displayed in dynamic graphs integrated into a story map² (figure 10).

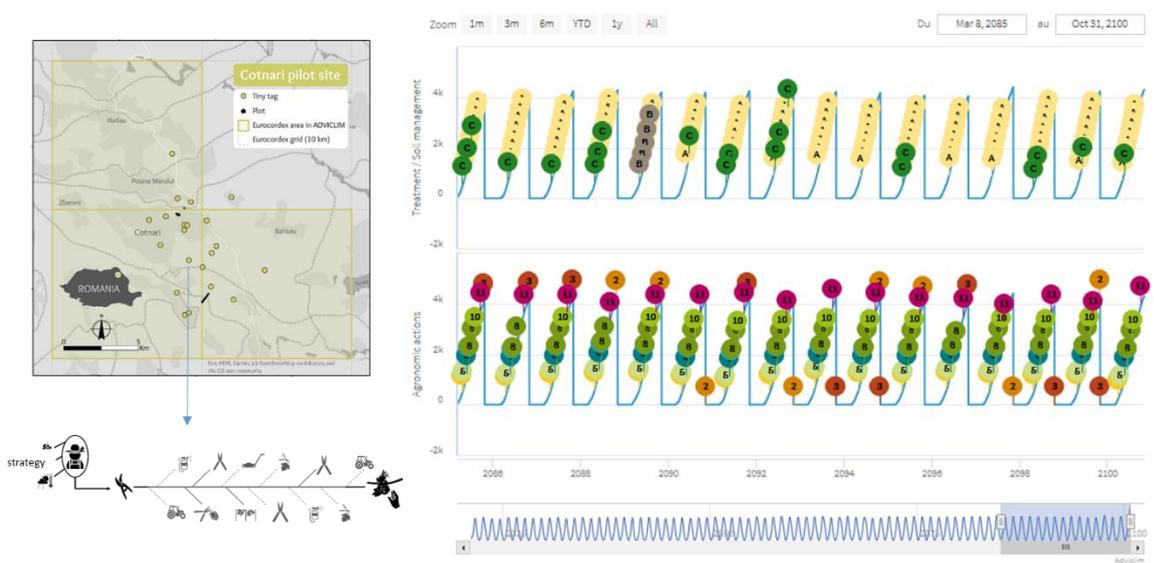


Figure 10: Agronomic action variability at plot scale in Cotnari pilot site for scenario 8.5

Simulation outputs highlight a strong variability in the number of actions according to the pilot site and the winegrower's production profile. The comparison of the number of actions on a global scale is not very relevant because the agronomic itinerary is very different depending on the vineyard and the style of wine produced.

At the local scale, for example at the Layon pilot site (figure 11), simulation results show a slight increase in the number of actions, especially for organic plots. This result is largely related to the increase in the number of fungicide treatments. In organic production, the use of contact products requires a high spray frequency during periods of pathogenic risk (a few days between each spray). In conventional production, by using systemic product, wine growers reduce significantly this frequency (usually at least 15 days between spraying).

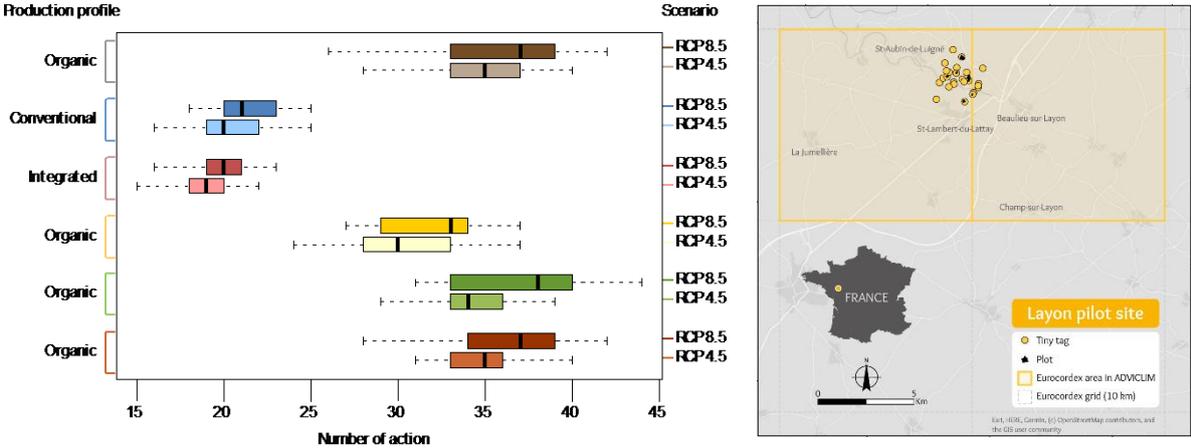


Figure 11: Comparison of agronomic action numbers between two climate change scenarios (RCP 4.5 and RCP 8.5) during 2030-2050 period for Coteaux du Layon pilot site

² A story map is a dynamic tool that allows end users to explore a subject through various communication tools (images, videos, interactive maps, data, figures, and text). The interactive document can be consulted at the following address <https://www.adviclim.eu/storymap>.

On pilot sites such as Cotnari or Geisenheim (figure 12) the simulation results indicate a relative stability of the agronomic itineraries in the medium term.

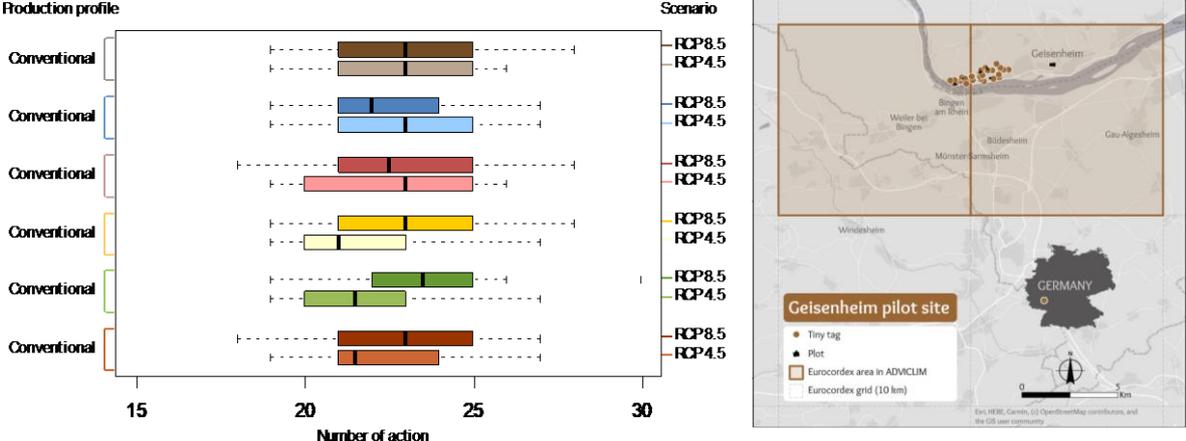


Figure 12: Comparison of agronomic action numbers between two climate change scenarios (RCP 4.5 and RCP 8.5) during 2030-2050 period for Geisenheim pilot site

These results show that with a changing climate, even if the risk of disease seems to be higher in most of the pilot sites, the increased earliness of the grapevine partly compensates this risk by reducing the exposure period to cryptogamic disease.



Adaptation strategies

If, according to simulation results, the variability of the agronomic itineraries seems to be moderate, climate change over the next few decades will require an adaptation of production systems to control the phenological cycle of the vine. With an expected increase in temperatures over the next century, the prospective simulations show that phenology will become earlier (as shown in table 2), regardless of the climate scenario.

One of the principal challenges for winegrowers will be to manage increasing temperatures in order to delay grapevine phenology. Indeed, optimal grape ripening should occur in Europe during the month of September. A too early onset of ripening will lead to unbalanced grape compositions. Increased early phenology can also lead to an increased risk of frost during bud-break and flowering period. Linking the results of the SEVE model with the climate projections of RCP 4.5 and 8.5 shows that the risk of spring frost may be significant in some sites such as Cotnari or Saint-Emilion due to an increased earliness of the vine in the future (figure 13).

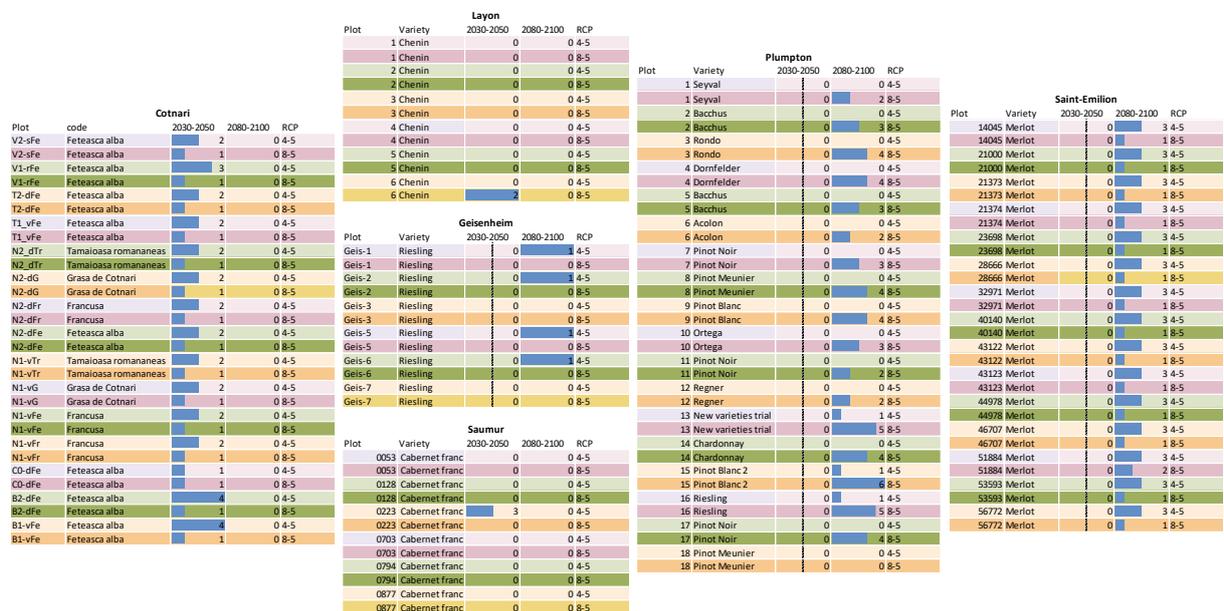


Figure 13: Projection of frost risk during bud-break and flowering according of two scenario of climate change (RCP 4.5 and RCP 8.5)

In some test plots the results show an occurrence between 20% and 30% of frost risk. Given the risks for the vines, this could lead winegrowers to use frost protection methods. In case of passive protection includes indirect methods (e.g., site and vine variety selection, pruning techniques) the choice of grape variety could lead to late-ripening varieties selection. As the incidence of late-spring frosts is highly variable over time, active protection based on direct method (e.g., wind machines, heaters, over-vine sprinklers), applied just before or during frost events, could be used by winegrowers.

There are several options that winegrowers can employ to manage phenological cycle variability and limit risk exposure of the vines (table 3). They vary from short-term and less effective adjustments in agronomic practices and harvest management practices to long-term and effective measures in varietal selection (e.g. clonal selection or choice in grapevine variety). As shown in table 3, adaptation strategies can be numerous depending on site

constraints and the profile of the winegrower (production system, end-products objective, etc.).

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

Table 3: Types of adaptive responses used by winegrowers to manage climate conditions

Most of these adaptation strategies were presented in the first deliverable of action B1 published in 2016 (<https://www.adviclim.eu/wp-content/uploads/2019/06/B1-Guidance-Manual.pdf>). In this second deliverable, the adaptation strategies of the plant material were more specifically targeted. In particular simulations were carried out to test the conditions for a change of grape variety. Within this perspective, the following adaptation rule has been implemented in the SEVE model: a change of grape variety potentially occurs when the technical maturity of the vine is reached 1 month before the current average maturity date at least 4 years out of 10. At global scale, the model outputs show that all sites are affected by a change of grape variety which occurs more or less early depending on local climatic conditions (figure 14)

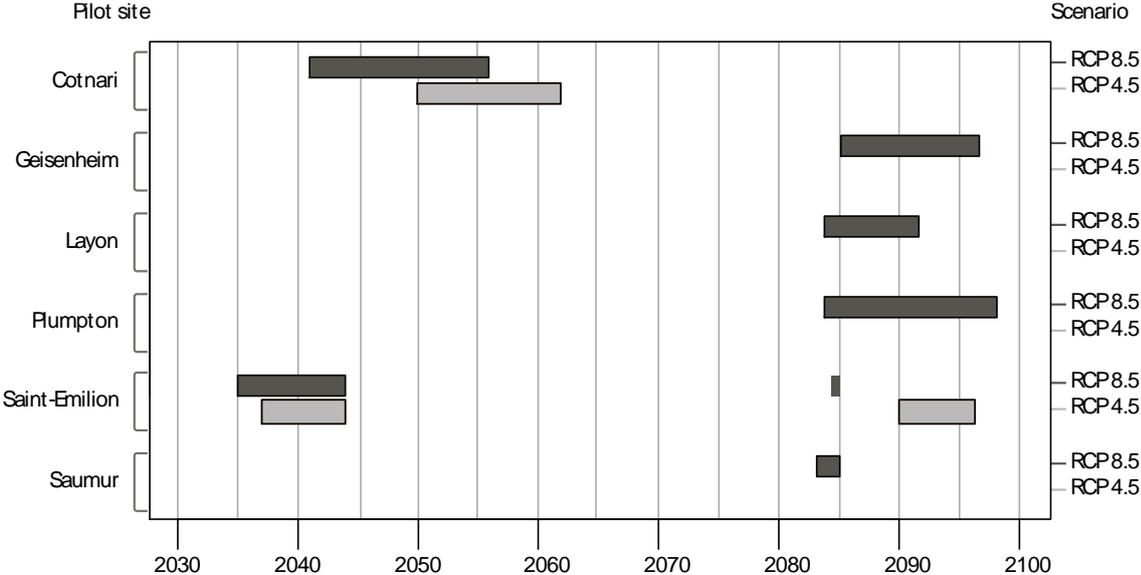


Figure 14: Potential period of vine variety change according to two climate change scenarios (RCP 4.5 and RCP 8.5)

On a local scale, the change of grape variety can take place at different periods depending on the initial variety cultivated in the plot and the differences in temperature observed in the vineyard concerned.

On the Cotnari pilot site for example (figure 15), differences of several years can be observed between changes of grape varieties. The choice of the replacement grape variety varies according to the style of wine targeted. In this vineyard the Merlot and Cabernet Sauvignon grape varieties could be suited to future climate projection and local environmental conditions.

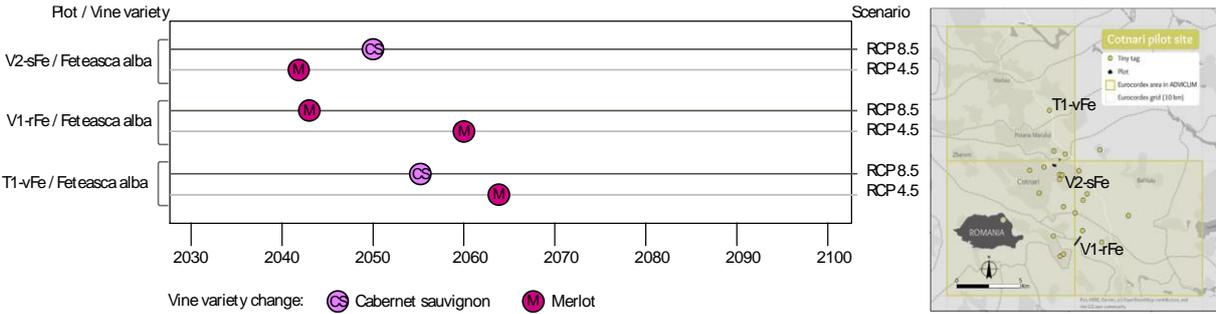


Figure 15: Comparison of variety change dates in three test plots in the Cotnari pilot site

On other vineyards such as Saint-Emilion the change of variety could occur twice during the century. (figure 16).

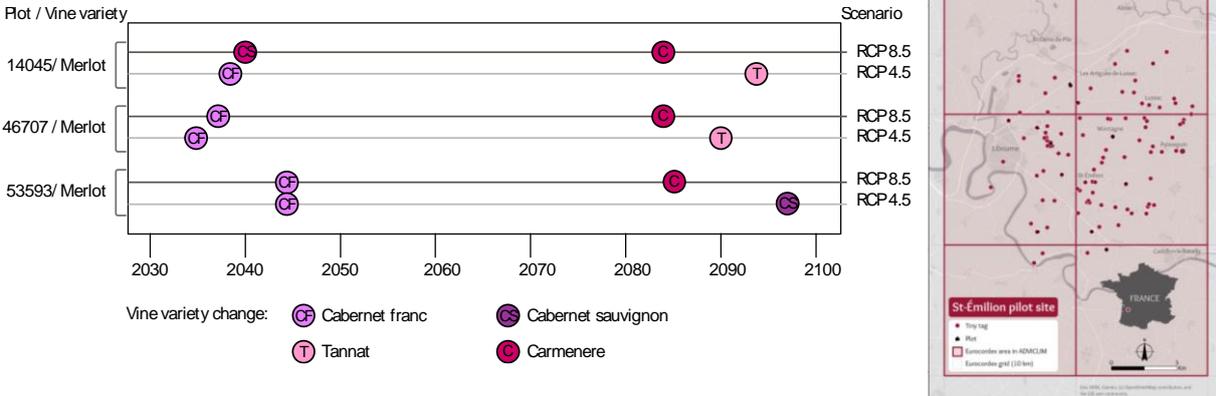


Figure 16: Comparison of variety change dates in three test plots in the Saint-Emilion pilot site

In a context of increasing temperatures, the change of plant material is carried out in favour of late-ripening varieties. If they can be found among the traditional varieties in some wine-growing regions, it might be necessary to use non-local varieties to adapt to the most pessimistic scenarios. In this case plant material adaptation is obviously difficult to implement in European wine growing regions with traditional appellations. In most of these appellations, winegrowers can only use local varieties.

These simulation results highlight the need for winegrowers to plan adaptation measures according to different scenarios and possible strategies. This implies a combination of annual and medium-term planned adaptations.

Thanks to simulation results provided by the B1 action, a potential adaptation sequence can be highlighted for each pilot site (figure 17).

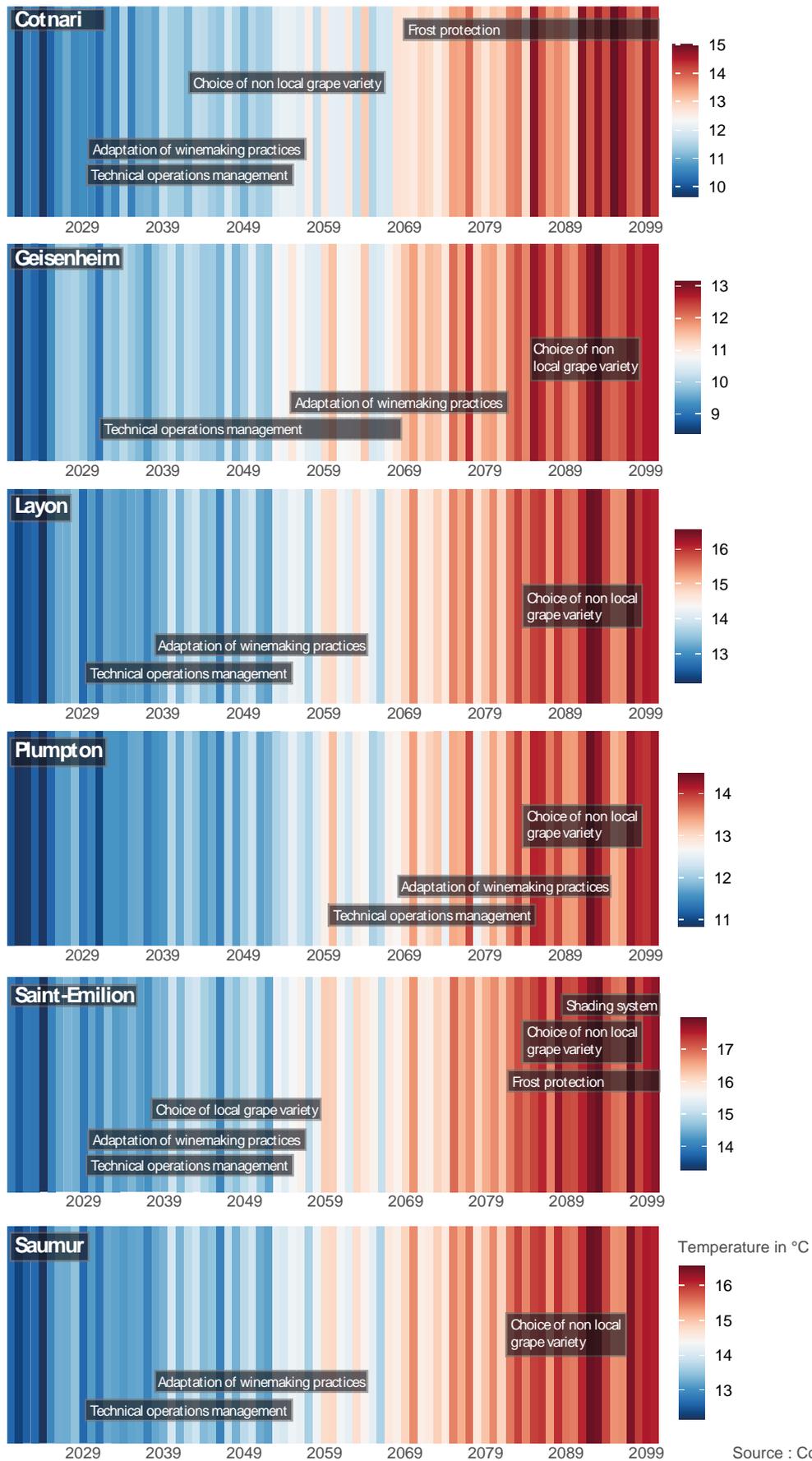


Figure 17: potential adaptation strategies on pilot site vineyards simulated by SEVE model

These results provide adaptation trajectories among a set of possible trajectories. Other adaptation strategies can be considered as illustrated in Table 3.

Whatever the strategy considered, the main difficulty is associated with the perception of climate change by winegrowers.

Therefore, despite a strong increase in temperatures over the next century, the results show that the inter-annual variability in climate conditions remain an important deciding factor of decision making. These results show that with a changing climate, the risk is that annual or daily climate variability may overshadow local winegrowers' perceptions of long term temperature and rainfall changes. That means future uncertainties for winegrowers, as they attempt to minimize annual variation in grape yield and quality, by adapting optimally their annual and especially perennial practices. The risk is that future adaptations in perennial practices will likely be limited by climate variability that will oblige wine growers to intensify even more their present soil management and canopy management practices. Within this perspective, simulation result provide by SEVE model indicate the need to find a coherent relationship between vineyard and plot scale to provide more clear guidelines on planning and adapting to uncertain long term climate changes, which is a major challenge for the wine industry.

Conclusion and perspectives

The modelling approach presented in this action addresses the impact of environmental conditions and constraints on grapevine behaviour and the dynamics of viticultural activities. Through the development of this modelling approach, the impact of climate variability on grapevine performance and winegrowers' production strategies was specifically targeted, both over time and space. The results obtained during the ADVICLIM project show that SEVE model is able to reproduce the dynamics of vine growing and agronomic choices and practices according to climate variability. In the context of climate change, such a dynamic and complex model will help to better assess potential impacts on viticulture and to frame adaptation solutions at different temporal and spatial scales.

Thanks to this approach, simulation outputs illustrate some potential agronomic strategies among a set of potential strategies. However, even if we used bias-corrected climate data, there is uncertainty in the data included in SEVE and the model at different scales propagates this uncertainty. Therefore, the results must be interpreted with caution given this uncertainty.

Many perspectives are still considered. They are mainly focused on improvements for assessing various adaptation measures on grapevine growth and grape quality. Technically, this means introducing feedback loops in the model in order to simulate the implications of viticultural practices on the grapevine (level of vigour, vine earliness, resistance to pathogens, etc.). The integration of other indicators including measuring the potential quality of grapes at harvest is also considered.

Several prototype based on SEVE model framework are under development in Europe (Spain), south America (Argentina) and New Zealand (International Research Project VINADAPT). We also plan to extend the story map to other pilot site in Europe.

Finally, a spatial optimization model is under development in a PhD hosted by UMR LETG team. Complementary to SEVE model, this approach will test several spatial configuration of vineyards in Brittany and New Zealand according to different climate change scenarios. The objective will be to identify well-suited agroclimatic pattern in the context of optimized adaptation to climate change.



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