

NATHALIE OLLAT AND JEAN-MARC TOUZARD, EDS

VINE, WINE AND CLIMATE CHANGE

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Nathalie Ollat
and Jean-Marc Touzard,
editors

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Preface

Climate change is a reality to which mankind must respond urgently in many sectors. However, current political initiatives on a global scale are not sufficient for a significant change to protect the climate and support sustainability. We as individuals have only limited options (but yes, we can make a contribution), and in a larger context, infrastructural, organizational and legal changes are necessary to move towards a low-carbon lifestyle to avoid continuous warming on the planet. Many initiatives to reduce carbon emissions are doomed to fail or cannot achieve the goals set as long as at the same time policies on a global scale subsidize fossil energy use with approximately USD 1 trillion per year! The questions of renewable energy use, sustainable building construction or water conservation and access to water are pertinent to the entire global population and it becomes more and more clear how dependent humans are on nature and weather (and on a longer timescale, climate).

Of all sectors that need to implement changes, agriculture is one of the most important ones because it is the basis for food production. Climate is a decisive factor for the cultivation of agricultural crops, from the geographical suitability to the effects on yield and quality. Throughout human history, these strong ties determined the cultural and economic development of regions, created local identities and have influenced migration and settlements. In the field of agriculture, these connections have their most intense expressions in the production of grapes and wine. Grapevines have been cultivated for several thousand years and during this long history specific growing regions were established, whose climatic conditions played a decisive role in the formation of specific wine characteristics from certain varieties. Over time, climate parameters (such as temperature) were used to delimit the boundaries of wine regions and to develop legal frameworks that are still present in the current definition of wine regions throughout the European Union for example. The "European experience" has been used as a model, in that climatic indices of different European wine regions were applied to non-European regions to determine general suitability and the choice of cultivars.

In the context of climate change, agriculture and therefore also viticulture are also contributing to greenhouse gas emissions and environmental pollution through cultivation practices but there is a potential for mitigation because soils can have substantial carbon storage capacities. At the same time it is also important to recognize that the grape and wine industry needs to reduce its environmental footprint well beyond mere field cultivation practices, including processing, packaging, logistics and many more areas.

The French grape and wine industry is unique among all global wine industries because of its economic value, the social impact, the tight regulations, the diversity of meso-climatical (regional) conditions, its terroir-based production idea, regional

specifications with respect to varietal use, cultural methods and product type conferring regional and local identities with a long history. Preserving this closely intertwined system in a changing climate under rapidly changing environmental, social and economic conditions is an enormous challenge. Contrary to previously managed crises such as phylloxera or the introduction of fungal diseases (powdery and downy mildew), where causal agents could be relatively fast identified and responded to, the current challenge (i.e. climate change) is global, occurs relatively slow (timescale of decades or longer), is for many not immediately evident (despite more and more signs of acceleration) and will develop most of its impact in the "distant uncertain" future. This makes it the more challenging to convince the entire industry including all stakeholders and the consumers, that an immediate reaction is required. And reacting now is of larger importance for the grape and wine industry than for other agricultural sectors because of the longevity of plantations, thus largely defining a product for 2050–2070 and may be beyond, by planting now.

Adaptation has such a regional, varied, social and economic diversity, as well as an array of institutional and regulatory (thus political) facets which need to be addressed to devise something like a national strategy including all stakeholders which comprises to some extent even the general public (like in grape-producing areas).

The current compilation from the LACCAVE initiative (it is more than a project) with different climatic analyses, definitions of regional environmental limitations and characterization of specific regional conditions, plant genetic, physiological and cultural systems adaptation studies, identification of disease threats, oenological responses to the observed and expected changes, consumer expectations, perceived socioeconomic consequences in different regions and the formulation of adaptation measures on different levels in the regional production chains including members of the industry and around is as unique as the French viti-vinicultural system.

This collection of initiatives around one large topic is special because it includes bidirectional knowledge transfer from science to the industry and back, which is very important to secure acceptance of results. LACCAVE is a unique and very comprehensive "pilot study" and in many ways can become a role model for grape- and wine-producing areas around the world in the methodological array of tools used, from climate and physiological models (natural sciences) to behavioural models and "Climathons" (socioeconomic sciences) to educational concepts. It is an example for how science in all dimensions can act together with authorities (local, regional, national), industry members and local populations to come up with a coherent plan for the future. And of course, the process is not finished yet.

System transformation to form the basis of resilience of an entire industry towards future environmental conditions is a task which needs to include all the facets of human anxiety and innovation. "Will viticultural areas have to move outside of their current boundaries (nomads)?", "should we change anything at all (being conservative)?", "let's be innovative", to "liberate the system completely (which would be equal to destroying the current "French connective system"). LACCAVE succeeded to devise a common strategy in a "democratic" system.

The goal is not to adapt and survive for a certain time with a traditional product for a certain price. The goal is to show ways for a long-term survival including concepts such as "agroecology", soil conservation, disease tolerant varieties, innovative water and energy management, etc. and, most importantly, implement the outlined strategies and solutions into educational formats at all levels. Because if we are not able to plant the need to change and the necessary tools to achieve change in the heads of the next generations, we will not succeed in managing the climate crises.

Hans Reiner Schultz,
President, Hochschule Geisenheim University (Germany)

General introduction

Nathalie Ollat and Jean-Marc Touzard

Climate change is a reality that impacts all of us and is changing our way of life on Earth. The findings of each successive IPCC[1] assessment report – the most recent being the sixth – are becoming increasingly alarming, hence the need to act with the utmost urgency (IPCC, 2023). Agriculture is on the front line, both as a major emitter of greenhouse gases and an industry highly impacted by its dependence on the climate. These links to the climate are of vital importance to the French viticulture and wine industry. Historically, they are in integral part of the concept of terroir and play an important role in the location of vineyards, the choice of grape varieties and practices, the definition of wine qualities, and the organization of wine markets (Dion, 1990). Climate change is upsetting a delicate balance that has developed over time and is part of the very foundations of an activity that has such a special place in the French economy and society (Ollat *et al.*, 2020, 2021). This poses a major challenge for everyone involved in the industry, from winegrowers to wine consumers, not to mention the researchers who produce knowledge about its various components.

The heatwave that hit France in 2003 brought home the challenges posed by climate change, leading researchers to begin looking into it the following year (Ollat *et al.*, 2020), with stakeholders in the viticulture and wine industry either supporting their research efforts or taking action themselves to assess their carbon impact. Meanwhile, wider scientific and political discussions at international conferences such as the Conferences of the Parties (COP) quickly established that measures to reduce greenhouse gas emissions would not be enough to curb climate change and that adaptation was becoming a key issue for agriculture and the food industry (Soussana, 2013). In 2011, for example, the French National Institute for Agricultural Research (now INRAE) set up a multidisciplinary framework called the Adaptation to Climate Change in Agriculture and Forestry (ACCAF) Metaprogramme to support projects looking into climate-change adaptation in agriculture and forestry (Caquet, 2017). Scientists involved in viticulture and wine, some of whom were already working on climate change projects, took the opportunity to put forward a project entitled LACCAVE: *Long-Term Impacts and Adaptation to Climate Change for Viticulture and Enology*. The main aim was to pull together all relevant research being conducted in France and to make the results more readily available to industry stakeholders (Ollat and Touzard, 2014). Published after 10 years of activity (and two IPCC reports), this book takes stock of the work conducted to date, offers a state of knowledge on the subject and reports on the approaches that have moved industry

1. Intergovernmental Panel on Climate Change, a body that advances knowledge on climate change.

stakeholders to action. It aims to appeal to a large number of readers, in keeping with the spirit of participation that has driven LACCAVE since its inception. It is divided into two main parts. The first comprises nine chapters describing the impacts of climate change on grapevine, soil and wine quality, followed by technical and geographical adaptation levers: the development and selection of new varieties, vine management, water management, oenological solutions and reference to climate variability in a given area for vineyard reorganization. The second part is made up of seven chapters that explore how industry stakeholders work with researchers and use the levers available to develop knowledge and strategies: the perception of impacts among winegrowers and consumers and the role of professional organizations, research, training and participatory approaches leading to the emergence of solutions at local level, the design of new winegrowing systems, and the creation of a national adaptation strategy. The two parts put forward a wide range of scientific contributions, with particular attention paid to the methods employed. Each chapter features in-depth details on experiments, systems, results and actions in special text boxes.

Changing climate a cause for concern

Since the advent of the twentieth century, the atmospheric concentration of CO_2 has risen by 40% (reaching 419 ppm in 2023), with almost half of this increase occurring in the last 30 years. As a result, air temperatures in France have increased by an average of nearly 1.8°C year on year, a process that has gathered pace since the 1980s, with every year since 1990 being warmer than the average since 1900, and the warmest years being 2014, 2018, 2020, 2022 and 2023 (Météo-France, 2024, figure Intro-1A). This in turn has led to an increase in soil temperatures up to a depth of 50 cm (Schultz, 2022). However, annual rainfall has shown little change, increasing slightly in the north of France and falling in the south, with more significant decreases depending on the season and region. In the Mediterranean region, the number of cycles in which winter precipitation (when soil water is recharged) fell below 200 mm increased during the period 1990–2021 (table Intro-1). Furthermore, an increase in potential evapotranspiration brought about by rising temperatures has been recorded at vineyards located at various latitudes across Europe (from Avignon to Geisenheim in Germany), although this is not a systematic occurrence (Schultz, 2017).

Compared to the 1976–2005 period, warming is set to continue without any significant difference between the various emissions scenarios that may play out between now and 2050 (+1°C to 1.5°C). In the most pessimistic scenario, temperatures in south-eastern France could rise by more than 5°C by the end of the twenty-first century, with a spectacular increase in the number of heatwave days (Corre *et al.*, 2021; figure Intro-1B and figure Intro-2). Precipitation trends cannot be predicted with any great certainty (Zito, 2021; Ollat *et al.*, 2021). Nevertheless, longer droughts are expected in the years ahead, particularly in southern and western France (Corre *et al.*, 2021). Some Europe-wide simulations point to a 10%–30% increase in actual evapotranspiration as early as 2050, with a water balance (rainfall minus potential evapotranspiration [PET]) that could fall by as much as 120 mm in southern regions (Cardell *et al.*, 2019). These projections are confirmed by the work of Zito *et al.* (2023), which provides the most recent simulations of climate and bioclimatic indicators for 21 French winegrowing regions on an 8×8 km grid. Any rise in temperature

Table Intro-1. Median winter (October to March) precipitation values over the historical period at French winegrowing sites and differences between the period before 1990 and the last 30 years. According to N. Saurin, AgroClim-INRAE data.

	Start of the series	Median […–1989] Recharge (mm)	Median [1990–2021] Recharge (mm)	Difference between [1990–2021] and […–1989] Recharge
Marseillan-Plage	1956	349.4	292.5	**–56.9**
Gruissan	1962	403.6	319.9	**–83.8**
Colmar	1973	213.2	233.3	20.1
Mauguio	1956	415.2	320.0	**–95.2**
Montreuil-Bellay	1977	334.8	308.5	–26.3
Fagnières	1971	312.3	295.1	–17.2
Avignon	1968	362.2	354.0	–8.2
Villenave-d'Ornon	1961	518.7	504.8	–14.0

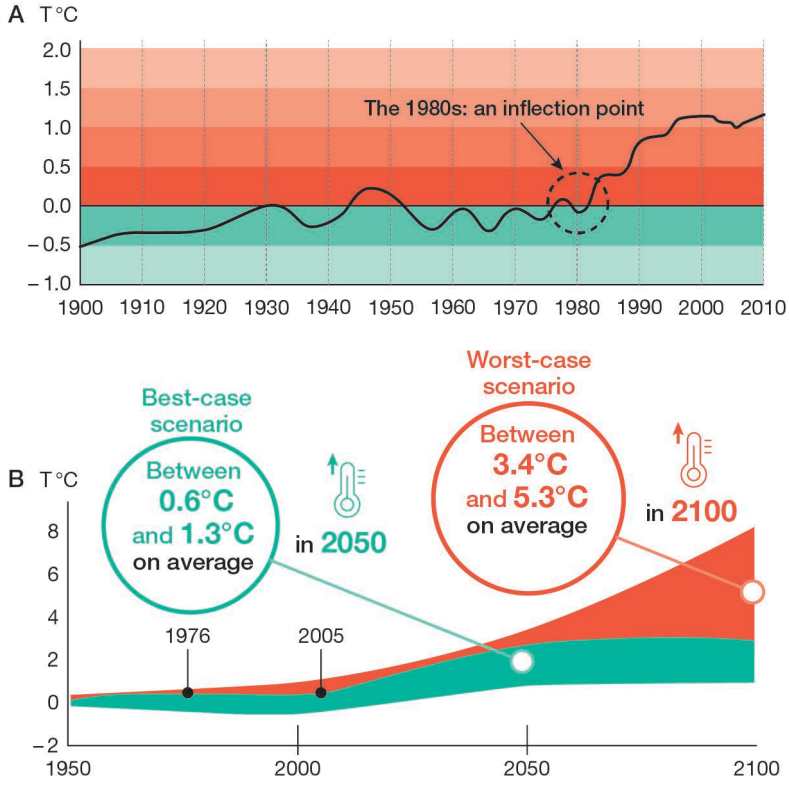

Figure Intro-1. Variations of average air temperature in France since 1900 (A) and simulated figures for the twenty-first century (B). The temperature has risen by almost 1.8°C over the last century and will continue to rise at a variable rate depending on greenhouse gas emissions scenarios. Increases are expressed in relation to the reference period (1976–2005).

also increases the frequency and intensity of extreme events such as storms and heatwaves, with impacts including the increased risk of fire, the destruction of infrastructure and ecosystems, and negative effects on human health (IPCC, 2023). These last few years are a perfect illustration of the gravity of the situation, both in France and globally.

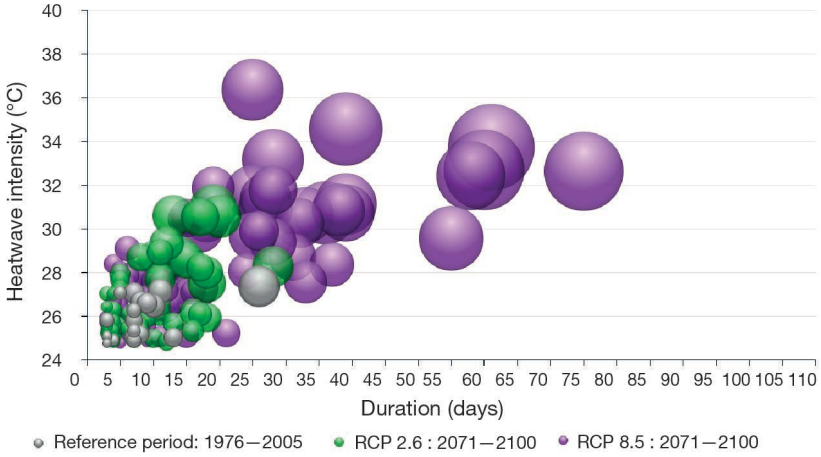

Figure Intro-2. Observed (1947–2018) and simulated (through to 2100) annual heatwave characteristics for different scenarios and time frames. Source: Météo-France.

The consequences in store for viticulture and wine – which have been noticeable since the 1980s – are a cause of great concern to industry stakeholders: harvests occurring up to 20 to 30 days earlier by the end of the twenty-first century (Zito *et al.*, 2023); a possible increase in the risk of spring frosts (Sgubin *et al.*, 2018; Bois *et al.*, 2023); temperature increases during grape ripening, affecting their winemaking potential (Van Leeuwen and Destrac-Irvine, 2017; Van Leeuwen *et al.*, 2022a); changes in the risks associated with diseases and pests, although these remain difficult to predict (Caubel *et al.*, 2014; Bois *et al.*, 2017; Zito, 2021); more frequent and more intense droughts, with an impact on yields (Lebon and García de Cortázar-Atauri, 2014). The current situation and forecasts are concerning for all traditional winegrowing regions, where winegrowers fear for their ability to retain markets and ensure their continuing financial sustainability. In some winegrowing areas, however, these new climate conditions could have less of a negative effect, such as in Alsace (Duchêne and Schneider, 2005) and the Loire Valley (Touzard *et al.*, 2020), at least until 2050. Furthermore, some regions not especially known for winegrowing at this moment in time are showing potential (Ollat *et al.*, 2016b), among them Brittany (Zavlyanova *et al.*, 2023), raising the prospect of a "new viticulture geography" by the end of the century.

The LACCAVE project: a systemic and participatory approach to adaptation

When it comes to exploring the issue of climate change adaptation, the specific characteristics of the viticulture and wine industry make it a unique and interesting subject for scientific research. The importance of wine production to the French economy is the backdrop to that. The industry employs many people directly and indirectly and accounts

for a significant chunk of French exports (nearly €15 billion worth in 2022). There is also a cultural side to its status, given its effects on tourism and France's appeal as a destination. The industry is also very well organized and regulated by the system of protected designations of origin and geographical indications, which provides a legal framework encompassing the location of vineyards, winegrowing technologies and practices, and wine quality and markets. The fact that environmental, technical, economic and political factors are closely interlinked means that innovations and the changes needed to adapt to them require an interdisciplinary approach as well as discussions to bring the issues of priorities and coordination within the industry more sharply into focus. The scale of long-term investment, ranging from the vineyard to intangible assets such as a wine's reputation, is so significant that stakeholders need to look several decades ahead into what the future of climate change might hold. Planting a vineyard today involves acquiring the knowledge needed to envisage the wine it could produce in 2050. All these issues combine to make this high added-value industry a model for a pluridisciplinary approach to the analysis of climate change adaptation (Ollat *et al.*, 2020).

LACCAVE brought together a scientific network of 22 laboratories affiliated with INRAE, France's National Centre for Scientific Research (CNRS), and the universities and *grandes écoles* located in the country's main winegrowing regions and covering an array of scientific disciplines – from climatology and social sciences to genetics, physiology, agronomy, oenology and pathology. The network also forged ties with FranceAgriMer, the French National Institute of Origin and Quality (INAO), the French Wine and Vine Institute (IFV), engineers from the country's chambers of agriculture, and representatives of France's main wine trade associations.

The project's scientific objectives were to explore the long-term impacts of climate change (2050) on grapevine cultivation and wine production at a regional level and to acquire knowledge for developing and evaluating adaptation innovations and strategies for these winegrowing areas. In line with the ACCAF metaprogramme priorities, the objectives were also to provide a structure for French research into these issues and make it more visible, the idea being to better respond to demand from industry stakeholders and, in a broader sense, to disseminate knowledge and thereby raise climate change awareness among these stakeholders and society in general.

Over 10 years, LACCAVE met these academic, organizational, expertise-related and developmental challenges thanks to a wide range of initiatives and outcomes. This positive dynamic was made possible by the very duration of the project. Targeted studies into different aspects of adaptation, from planting material to analysis of consumer behaviour, were conducted over a sufficiently long period for a perennial crop and, ultimately, for industry stakeholders to take note of the climate issue. Other more methodological studies have yielded indicators, tools and models for enhancing simulations at a local level, assessing risks and mapping out adaptation. Internal think-tank seminars have led to more systemic thinking on key issues relating to adaptation, such as water and soil management. Participatory approaches have been rolled out gradually to help identify solutions at a local level, co-create more resilient systems, and conduct a foresight study leading to the development of a national industry-adaptation strategy. Finally, the project also included science events open to industry stakeholders – such as trade fairs – and to the international scientific community, namely with the organization of two international conferences and the development of several European projects.

In mapping out the adaptation process, LACCAVE focused mostly on 2050, by which time the projected temperature increases would be no more than 2°C higher than the reference period (1976–2005), even though several local-level climate simulations have also been conducted for the end of the twenty-first century (Neethling, 2016; de Rességuier *et al.*, 2020; Zito, 2021; Zavlyanova *et al.*, 2023; Zito *et al.*, 2023). It is with this timeline in mind that the project's participants worked together to create a shared vision, an analytical framework and methods that will bring about the requisite interdisciplinary approach to respond to the need for adaptation knowledge. They soon agreed that climate change is an ongoing and multidimensional process, that a great deal of uncertainty surrounds the forms it will take in the future, which vary at local level, that its impacts are global (not least on resources and ecosystems), and that adaptation must be viewed broadly, including biological processes driven by human action in a number of fields and scales (Viguié *et al.*, 2014).

The LACCAVE community thus adopted a common definition of adaptation, which is regarded as all the processes and actions that a society, region or industry implements to modify its activities in response to observed or expected climate changes, thereby minimizing the negative effects of this change and maximizing its beneficial effects (Hallegate *et al.*, 2011; IPCC, 2014; Caquet, 2017). As such, adaptation must be systemic and involve the analysis of impacts, vulnerability and risks on various spatial and temporal scales, by combining technical levers (Barbeau *et al.*, 2014), and also giving thought to the location of vineyards, rethinking business strategies and considering the growth of the industry through its markets, institutions, regulations and the development of technical and scientific knowledge (Viguié *et al.*, 2014; figure Intro-3). It was clear from the outset that there would be no single solution, such as a technological fix, and that different levers would have to be pulled together as part of strategies that could be overseen within a "sectoral system of innovation and adaptation" (Boyer and Touzard, 2021).

In general terms, LACCAVE favoured anticipation as a means of adaptation rather than reaction to the proven effects of climate change (Viguié *et al.*, 2014). The project also highlighted the importance of risk perception and the conditions of acceptance of change by stakeholders in the value chain (from producer to consumer), which are crucial to getting them to commit to adaptive strategies (Teil, 2017; Neethling, 2016; Boyer and Touzard, 2021). These issues are dealt with in chapters II-1 and II-2 of this book. The scale of the changes needed for adaptation has also been considered: incremental changes, such as modifying cultivation or winemaking practices, can no doubt enhance the short-term resilience of winegrowing businesses, but implementing them one after another may not suffice and could hinder long-term adaptation (Viguié *et al.*, 2014; Caquet, 2017). In the short term, there is unquestionably a need to consider no-regrets measures, namely those that are worthwhile regardless of the extent of climate change. Agroecology and agronomic practices preventing erosion fall into this category. The flexibility and reversibility of resources committed to adaptation should also be factored in, such as by diversifying grape varieties or making institutional changes, as opposed to investing in costly technological solutions that risk locking in technical systems (Viguié *et al.*, 2014). Such is the importance of the long term for a perennial crop and the intensity of the climate change predicted for the second half of the twenty-first century that adaptation should be seen as a continuous, systemic and transformational process, which may involve radical changes such as a general renewal of grape varieties or a major relocation of French vineyards (Caquet, 2017; figure Intro-4). Given the intensity and speed of climate change, these potential responses should be