VITICULTURE AND ADAPTATION TO CLIMATE CHANGE

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The aim of this article is to lay out a series of issues of current concern to researchers in the social sciences, regarding the impact of climate change on the vine and wine sector. The challenge lies in evaluating the cost of transition from one system to another through an integration of the direct and indirect effects of climate change. This adaptation, whether reactive or anticipatory, combines technical and organisational innovations with localisation strategies and institutional changes. Such actions could either try to maintain the existing situation as much as possible or could try to bifurcate towards deep changes, entailing very different costs. Given the multitude of uncertainties at play, not to mention the necessity for continuous adaptation to an ever-changing climate, these costs are hard to quantify. This article will illustrate two sets of measures for wine cultivation adaptation: 'no regrets' measures, which offer immediate benefits, and 'reversible and flexible' measures, which limit the inertia of wine-cultivating systems. In spite of the challenges, what stands out is the evident re-enforcement resulting from the collaboration between researchers and political and economic actors. In the field of wine cultivation, these collaborations can follow two paths: the study of the diversity of existing wine-growing systems and genetic resources or the possibility of more radical technological and social experimentation.

INTRODUCTION

Wine cultivation depends heavily on climate, which influences both the development of the vine and the quality of the wine that is produced from its grapes, and for this reason, it has become a point of reference for the study of the effects of climate change (Jones and Webb, 2010; Seguin, 2010). On top of this, it can also act as a laboratory of sorts for the analysis of climate change adaptation strategies. The many levers that have helped grape and wine production to evolve have indeed combined with technical innovations, localisation strategies and institutional changes (Holland and Smit, 2010; Ollat and Touzard, 2011). To pursue these issues further, we will consider here a series of questions raised by the social sciences concerning adaptation to climate change and apply them to climate change and the vine. After a brief summary of the characteristics of climate change and its impact on human activities, we will present the lessons learned from research into this adaptation and the questions it raises for wine cultivation. We will then outline how different types of robust measures could be appropriately applied to wine cultivation.

A MAJOR CHANGE

Climate change will result in a rapid evolution of the climate, an evolution that can be evaluated with the aid of national and international climactic projections (see for instance Jouzel *et al.*, 2012 for climate evolution in France). As it is not possible to predict future greenhouse gas (GHG) emissions, projections are based on scenarios, that is to say, possible changes in global emissions up to the year 2100. Following this method the IPCC (Intergovernmental Panel on Climate Change) constructed a collection of contrasting scenarios for GHG emissions to serve as a basis for international exercises in climate simulation. A first set was constructed in 1990 (Nakicenovic *et al.*, 2000), and it was recently enriched by a new collection of scenarios which is used for climate projections of the latest IPCC report (Moss *et al.*, 2008; Moss *et al.*, 2010). An example of such a scenario is the SRES A2 scenario, which is frequently used as a reference; it presumes a rapid increase in global population and economy, an absence of climate policies, and a considerable increase in GHG emissions, consistent with current trends. The projections based on this scenario forecast an average increase in temperature of about 3 °C by the end of the century (IPCC, 2007).

This increase in temperature may initially appear to be relatively small. It is small, indeed, when compared with daily and between-season temperature variation. We must not, however, be fooled by these figures, as the variation in climate associated with this variation in temperature leads to profound changes in precipitations and meteorological extremes that do not show up on this one indicator.

A good illustration can be found in the work of Hallegatte *et al.* (2007), who investigated the similarities between a selection of large European cities in terms of temperatures and precipitations, as projected by two climactic models of the A2 emission scenario. From the simulations presented in Figure 1 and Figure 2 (the Hadley Centre and Météo-France, respectively), it can be conjectured that in 2100, Paris will have the same climate as Cordoba (southern Spain) and Bordeaux (southwestern France) have now. The climate of

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Marseille might also approach that of Cordoba or Greece. This approach makes it easier to anticipate the adaptation France needs to make, based on this climate forecast.

CONSEQUENCES FOR HUMAN SOCIETY

Why is climate change a serious issue? In fact, putting aside certain extreme cases (e.g., desert climates), it would be hard to argue that some climates are better adapted for man than others, and it is difficult to justify the claim that future climates will be more detrimental than current climates. Taking the above example again, there is no reason to believe that the climate of Cordoba would be worse for Parisians than Paris's current climate.

On the other hand, lifestyle and infrastructure differ greatly between these two cities, as do production and agricultural techniques in surrounding areas. They are adapted to their respective local climate. The situation becomes serious when, for one reason or another, people are not well adapted to their climate. The heat wave of 2003 is a very good illustration: the high temperatures resulted in significant damage in Paris (Hémon and Jougla, 2004), whereas these corresponded to normal summer temperatures in the south of Spain, where they do not lead to such tragic consequences (Hallegatte *et al.*, 2007).

The same applies to wine cultivation. Optimal climatic conditions for fine quality wines are diverse, as can be illustrated by Moselle in Germany, Burgundy, Bordeaux or the Cotes du Rhone in France, and the Napa Valley in California. The choice of grape variety, cultivation and wine-making techniques, and the laying out and localisation of plots have allowed wine production to extend across a wide range of soil and climate conditions (Tonietto and Carbonneau, 2004) and to respond to market demands, which value differentiation between products. Climate change is already affecting most wine-growing regions, with effects

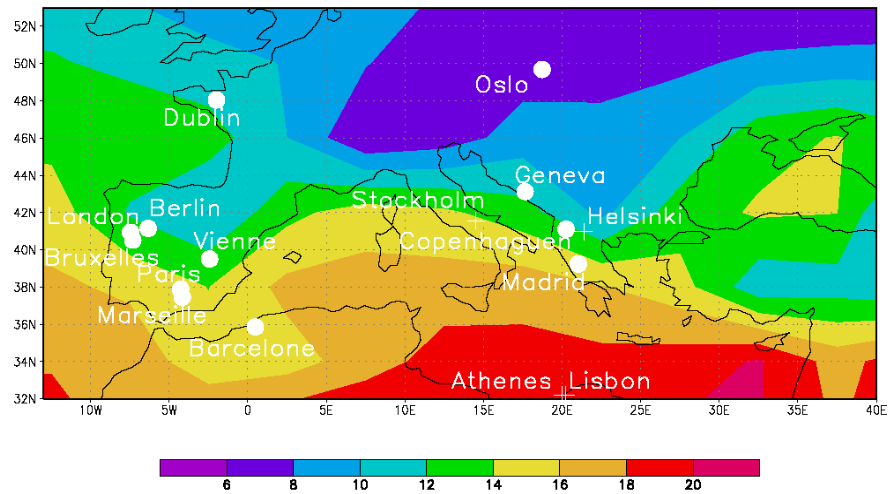

Figure 1 - Climactic analogues in 2070, Hadley Centre model, scenario SRES A2 (Source: Hallegatte *et al.*., 2007).

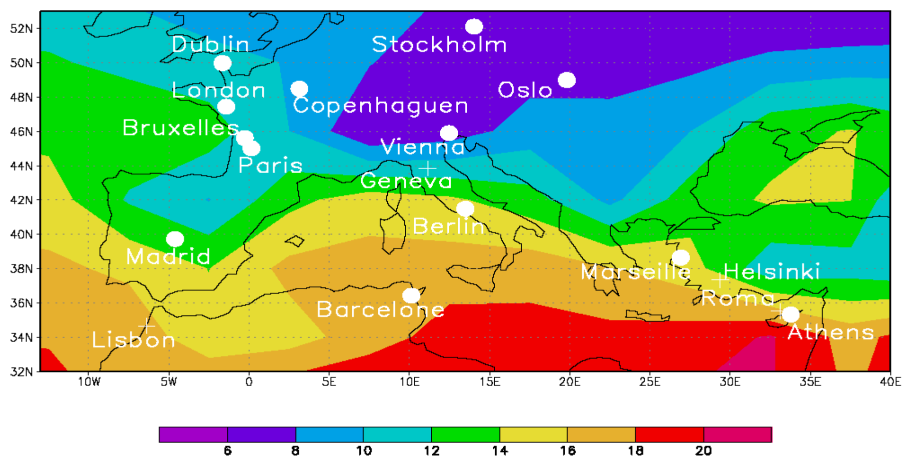

Figure 2 - Climactic analogues in 2070, Météo-France model, scenario SRES A2 (Source: Hallegatte *et al.*, 2007).

on the date of harvest (earlier), the composition of grapes and wine (higher alcohol content), and, to varying degrees, the vine's water comfort, crop development and yield. These effects do not necessarily threaten vine's viability or grape production, but they do raise questions about wine-cultivating systems and established quality. However, the transition from one production system to another in order to maintain or regain a quality/yield ratio that will be economically viable raises uncertainties and concerns over the likely cost. One of the principal challenges climate change presents is therefore to know if and how the transition can be managed, what investment it will call for, and how will regions succeed in making the transition from being adapted to current climate conditions to being adapted to projected future conditions for the next few decades.

There are some further difficulties : if it is never simple to adapt human activities, it should not be forgotten that it is not humanity alone that will have to adapt. Flora and fauna, and more generally the ecosystems that surround us, must also adjust, and it is by no means sure that they will survive unscathed, in view of the high rate of climate change when compared to geological climate change. Ecosystems operate in a very integrated manner, and the disappearance of certain species may set off a chain reaction amongst other species. These changes, which may be wide-ranging and extremely difficult to predict (IPCC, 2007), will also have an impact on human society, in addition to the direct impact of climate variation. We must therefore adapt to this double change : the change in climate and the change in the environment caused by climate change.

There are two ways of approaching adaptation to all these changes (Smit *et al.*, 2000). Adaptation can be reactive, that is to say, an ex-post response to an observed impact of climate change. It can equally be anticipative, that is to say, planned for and put in place before adverse impacts occur, with the aim of limiting the vulnerability of existing productive, social and ecological systems. From a political point of view, anticipative management is often more difficult to put in place than reactive management, but the associated gains are generally much greater (Hallegatte *et al.*, 2011 ; Hallegatte, 2010).

HOW CAN WINE CULTIVATION BE ADAPTED TO CLIMATE CHANGE ?

Approaches to climate change adaptation can broadly be defined as 'the set of actions and processes (technical change, organisational change, localisation) that societies must take to limit the negative impacts of the changes and maximize their beneficial effects' (De Perthuis, 2010 ; Hallegatte, 2010). In the case of wine cultivation, different types of adaptive actions exist, which are very different in nature and scope. They can be identified for example by reconsidering the human interventions that have shaped the current diversity of cultivated vines, sometimes in extreme conditions (e.g., in mountain and tropical areas).

First, **technical changes** are possible at different stages of the production chain : the choice of grape variety and its rootstock can improve resistance to drought, hold back the advance of the maturity date and modify the sugar content of the fruit (Duchêne *et al.*, 2010) ; new pruning methods can affect the exposure of the fruit and the micro-climate of the canopy (Jones *et al.*, 2005) ; irrigation can optimise the water balance (Carbonneau and Ojeda, 2012) ; and oenological practices can limit the 'defects' associated with climate change (e.g., reduction in alcohol content) or promote new aromatic flavours (Holland and Smit, 2010). There are potentially many variations of these technical innovations, with different costs and different levels of uncertainty regarding their effects on the wine production system and the quality of wines produced. One of the challenges is to anticipate their effects and to test them locally, which cannot be fully evaluated ex-ante.

These technical changes are generally tied to **organisational and localisation changes**, which constitute other levers of adaptation (Ollat and Touzard, 2011). Thus, the choice of vineyard management practices, the reorganisation of grape harvest (depending on maturity and temperature conditions) or the adoption of new rules, for example regarding irrigation, can be decisive. Localisation strategies are also an integral part of adaptation. They can benefit from soil and climate heterogeneity within the region. They can also lead to the consideration of relocating vineyards on more important geographic scales (Hannah *et al.*, 2013).

Technical, organisational and localisation changes fall within **institutional transformations and cognitive processes**, which wine cultivators can leverage by means of collective or political actions. As wine cultivation practices and vineyard localisation are regulated through a system of geographic indications, the development of that system becomes a powerful lever in implementing and guiding adaptation. Behind these changes, the development of new expertise and capabilities for action are being affected. Training, access to information, public and private investment in R&D, and development of cooperative ties between wine-growers and researchers are thus levers of adaptation, just as the development of consumer knowledge and preference are in the wine market.

Many solutions therefore exist. However, the true question when choosing which responses to adopt is the consideration of which changes would be considered 'acceptable'. Changing the grape variety, relocating the vineyards, and even changing the economic model and abandoning wine cultivation can all be considered, or rejected, as measures of adaptation, depending on the point of view. Naturally, the larger the definition of adaptation is, the greater the number of levers that come into play, and the easier adaptation will be. One extreme case arises when the choice is between adaptation 'at the margins', which endorses all possible responses to maintain things as they are, and 'bifurcation' towards new activities or new locations. For example, this question is pressing for ski resorts at low and medium altitude, which risk being unable to offer ski services in the future (Hallegatte *et al.*, 2011). It is also at the heart of issues facing traditional wine-growing regions and future wine-growing regions (Hannah *et al.*, 2013).

Selecting the right action, or program of action, is not easy. This require to identify the costs and the benefits. Both of them can be difficult to assess, as they do not only include a financial dimension, but also cultural and social ones. It should also not be forgotten that every climate adaptation policy carries, on the one hand, costs, and, on the other hand, residual impacts of climate change, that is to say, impacts that will remain after the adaptation measures have been applied. The choice between different adaptation policies, and between adaptations 'at the margins' and 'bifurcations', in particular, is made by weighing both sides of the question.

IN THE FACE OF UNCERTAINTY AND IRREVERSIBILITY, HOW CAN MEASURES FOR ADAPTATION BE CHOSEN ?

A certain number of general problems, however, make this analysis extremely difficult.

Firstly, the climate is continuously changing. Consequently, the objective is not to be perfectly adapted to the predicted climate of 2050 or 2100, but to be adapted to a ceaseless change. Wine-making practices, and more broadly, value chain organisation, cannot change overnight. The aim for the coming century is to succeed in keeping pace with climate change. We must therefore be careful that the adaptation measures that are effective for moderate warming will not constrain future action or have negative consequences in the long-term, when warming will be greater. For example, the establishment of a vineyard dependant on an irrigation system can hit a wall if the source of water is itself threatened by the change in climate. Also, massive replanting of a variety of vine that is known to reach fruition later but that does not have re-enforced resistance against summer dryness could prove to be catastrophic. These examples are under the title 'mal-adaptation', i.e., adaptation measures that exacerbate, rather than reduce, vulnerability (IPCC, 2007).

A second difficulty is the fact that it is not known precisely what the future climate will be. This uncertainty has two very different origins : our incomplete knowledge of climate on the one hand, and, on the other, the inability to predict exactly what GHG emissions will be in the future. These uncertainties in climatic projections increase as we consider local scales or intra-annual variation in temperature and rainfall, which is crucial to wine cultivation and quality. A comparison between Figures 1 and 2 gives a good idea of the uncertainty caused by our incomplete knowledge of the climate ; it shows two different projections from two different climate models of the same emission scenario.

Faced with these uncertainties, how should methods of adaptation be chosen ? Should they be radical or at the margins ? How can a decision be made for an investment that will take many decades to pay off ? One solution is to err on the side of caution and systematically consider the worst-case scenario. This solution makes sense but is difficult to apply in practice because the costs are often extremely high and there is the risk of paying too high a price for a result that does not justify it.

A more flexible approach involves limiting the number of possible scenarios to those in which the situation is considered unacceptable (Lempert and Collins, 2007 ; Hallegatte *et al.*, 2011), the 'unacceptable' standard being defined by a political decision. This approach identifies uncertainty and puts robust measures in place to address it (Hallegatte, 2009). Indeed, measures exist that are positive in a great number of scenarios, including the most extreme cases, and incur only very moderate costs in the other scenarios (Barnett, 2001 ; Heltberg *et al.*, 2009 ; Wilby and Dessai, 2010). Two important categories of such measures can be highlighted : 'no regrets' measures and 'reversible and flexible' measures.

'NO REGRETS' MEASURES

A first approach works with the fact that we are not perfectly adapted to our current climate and are already vulnerable to a certain number of environmental problems : biodiversity is threatened by the consequences of numerous human activities, water is frequently consumed in a non-sustainable fashion, and a significant percentage of the population lives in flood risk areas. Projected climate change consequences will, in many cases, be a worsening of these already existing problems ; for example, water resources will likely diminish in areas where they are now misused, and the frequency of floods will increase in a certain number of areas that are already prone to flooding.

Consequently, one effective adaptation measure is to start managing the current situation better. This is what is called a 'no regrets' measure, that is to say, the co-benefits themselves justify putting the measures in place, and thus the impact will be positive, irrespective of the envisaged scenario. These measures are not easy to put in place (if they were, it would have been done already) and do not allow for adaptation to all the impacts of climate change, but they constitute an effective first step. In the case of wine cultivation, an investment in technology that will help reduce alcohol content could fit into this category, at least in the case of the standard wines from Mediterranean Europe. An increase in the percentage of alcohol is in fact already penalised in many markets, and being able to reduce alcohol content can increase the saleability of wines in these markets as well as anticipate a trend that will continue. Even those actions aimed at preserving the soil and increasing its level of organic matter are likely to have quite rapid beneficial effects on the vine and re-enforce the image of wine as a natural product, while limiting the effects of more sporadic rainfall.

Another example of measure consists in investing, when the opportunity presents itself, in security margins. In some cases, the cost of adapting to worst scenarios, or at least to extreme ones, is not very high. It can therefore be useful to do it. Agronomic practices and landscaping that can limit erosion under heavy rain events illustrates this. In the case of an overestimation of the impacts of climate change, the cost would not be high, but the gain might be considerable (Hallegatte, 2009).

'FLEXIBLE AND REVERSIBLE' MEASURES

In the face of any change, the great challenge is the management of inertia. We are vulnerable to climate change if we do not succeed in adapting ourselves at the same pace. A second approach gives preference to measures that limit this inertia and that can be adjusted or cancelled when new information becomes available, or in other words, flexible or reversible measures.

This could take the form, for example, of reducing the length of the investment period and trying, as far as possible, to avoid long-term investments. An investment that is expected to be profitable in 10 years will in fact be less affected by the diverse possible changes in climate than an investment that is expected to be profitable in 20 years or more. In the first case, it is possible to take into account how climate has actually evolved during the first 10 years and design the next 10-year investment accordingly. This would be impossible in the second case.

In the field of wine cultivation, a parallel can be made between the amortisation period of a plantation and the choice of oenological equipment, or irrigation, for which there are different technological options that are deployable to a greater or lesser extent. As one of the characteristics of climate change is also the escalation of inter-annual variability and its effects on vintage, the decisions aimed at reducing or endorsing these effects will promote flexibility in wine-growing systems. Investment in diversification of vine varieties, as well as wine-making techniques and the wines themselves, increases the range of options, experiments and possible blends, in spite of vicissitudes in climate and in the market.

Another type of 'flexible measure' is to favour the use, whenever possible, of reversible strategies, such as financial or institutional adaptation strategies, over investments in costly technological solutions. Such strategies can indeed be adapted, changed or cancelled at low cost and almost no money lost, whereas in the case of a costly investment, turning back means that the money invested is lost. Illustrative examples come from different fields outside viticulture, such as for instance the increased risk of flooding in many areas due to climate change. It is possible to protect against flood risk, either by restricting land-use plans and banning development in future potential flood risk areas, or by constructing flood defences (dykes) (Hansen *et al.*, 2011). The big advantage of the first solution is that land-use plans can be modified if the risk factor has been overestimated, whereas once an oversized dyke has been built, the money is lost.

CONCLUSION

Over and above technological and agronomic problems, the conception and selection of adaptation measures to climate change raise specific difficulties :

- Climate change is an evolving process : knowing how to adapt to a new climate is not enough, we need to know how to adapt to a climate that is continually changing ;

- The exact characteristics of the future climate are not known with great precision, partly because it is not possible to predict what our future GHG emissions will be, and partly because its expression at local scale, so critical to viticulture, is subject to multiple parameters which interact with each other ;

- The indirect effects of climate change on the resources and ecosystems that condition an activity add another level of uncertainty. For example, in viticulture this applies to water supply and to pests and diseases ;

- Political, institutional and even cultural conditions for vine adaptation are wide open and do not only encompass innovation or delocalisation but also the development of consumer preferences.

Adaptation strategies to climate change must explicitly take into account these difficulties. That does not, however, make the task impossible. A number of robust strategies for planning ahead exist, robust enough to take on the continuing changes in climate as well as the range of possibilities for the climate of tomorrow. All these measures come at a price in the short term, and it is not simple to put them in place. Thus, amongst the measures that we have listed, reducing the duration of the lifespan of investments generally leads to less profitable choices of investments. Investing at the margins of security is not free and does not come with short-term gains. Reversible strategies are less easy to put in place or to enforce. The cost, however, should be seen as an insurance which you pay initially, but which limits the possibility of future losses.

Because of the time-scale of climate change, it is unfortunately more and more difficult to have feedback and to learn from experience, and so we are forced to anticipate (Hallegatte *et al.*, 2011). Waiting to see which adaptation strategies have worked elsewhere increases the risk of acting too late. Research and long-term planning, the exchange of ideas, and collaborations between actors can, however, facilitate the process. For wine cultivation, two important lines of approach can direct the desired cooperation between scientists, wine-growers and political decision-makers: firstly, continue studying and comparing the great diversity of current wine-producing systems as well as the existing genetic resources that have resulted from the historic adaptation of viticulture in different climates, as this diversity will in all probability cover the situations expected from now until the end of the 21st century, and secondly, conceive and experiment with more radical options, including biotechnologies and agro-ecological and social innovations. The history of vine and wine is precisely one of a series of innovations that are part of the technological and cultural evolution of societies.

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