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Viticulture under climate change: understanding vulnerability and adaptive capacity of wineries and growers. A case study in *El Penedès* region, Catalonia.

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Abstract

Climate change may pose challenges and opportunities to viticulture, and much research has focused in studying the likely impacts on grapes and wine production in different regions worldwide. This study assesses the vulnerability and adaptive capacity of the viticulture sector under changing climate conditions, based on a case study in *El Penedès* region, Catalonia. Farm assets, livelihood strategies, farmer-market interactions and climate changes perceptions are analysed through semi-structured interviews with different types of wineries and growers. Both types of actors are equally exposed to biophysical stressors but unevenly affected by socio-economic changes. While wineries are vulnerable because of the current economic crisis and the lack of diversification of their work, which may affect their income or production, growers are mainly affected by the low prices of their products and the lack of fix contracts. These socioeconomic stressors strongly condition their capacity to adapt to climate change, meaning that growers prioritize their immediate income problems, rather than future socioeconomic or climate threats. Therefore, growers undertake reactive adaptation to climate changing conditions, mainly based on ancient knowledge, whilst wineries combine both reactive and anticipatory adaptation practices. These circumstances should be addressed in order to allow better anticipatory adaptation to be implemented, thus avoiding future climate threats.

1. Introduction

Climate change is known to be one of the most important challenges that humanity will have to face this century. Agriculture is considered to be one of the most potentially affected economic sectors, due to alterations in rainfall and temperature patterns, which may in turn affect seedling, growing and harvesting conditions. Climate change is expected to present both risks and opportunities for agricultural systems depending on the concrete crop and territory (Kimball *et al.*, 2002; Fischer *et al.*, 2005), and research has proved that its effects are already being experienced (e.g. Fischer *et al.*, 2008; Rosenzweig & Hillel, 1998; Adams *et al.*, 1990; Morton, 2007).

Climate influence on agribusiness is at its most evident with viticulture, due to the narrow climate range where vine grow, and the even narrower suitable niche for every grape variety. Interest and research on the impacts of climate change in viticulture has burgeoned over the last decade, and many different studies can be found (e.g. Schultz, 2000; Jones *et al.*, 2005; Webb *et al.*, 2007, Kenny & Harrison, 1992; Malheiro *et al.*, 2010; Jones & Webb, 2010; Battaglini *et al.*, 2009 and Mira de Orduña, 2010). Due to the concrete characteristics needed for optimum quality and production of winegrapes, vine is thought to represent an early-warning system for problems that all food crops may confront. Furthermore, wine has a broad and intense economical and cultural importance, and changes in quality or shifts in varieties could lead to changes in regional or global market suitability (White *et al.*, 2006; Jones & Webb, 2010).

Therefore, climate and socioeconomic stressors challenge agricultural systems that, in turn, try to adapt to such stressors. Adaptation in agriculture is already being studied and occurring in different parts of the world (e.g. Wang *et al.*, 2013; Reidsma *et al.*, 2010 & Chikozho, 2010). Among this sector, viticulture is also being analysed (e.g. Belliveau *et al.*, 2006; Lereboullet *et al.*, 2013 & Bernetti *et al.*, 2012), mostly focusing on regional adaptation. Many studies on viticulture highlight the importance of having both a socioeconomic and a biophysical perspective, since the sector is vulnerable to conditions that not only affect crop yield, but also affect its ability to compete in or sell in markets. These interactions shape decisions and management practices, allowing for different responses depending on the combination of stressors and circumstances (Bernetti *et al.*, 2006).

Assessing vulnerability is thought to be important, as it enables the identification of people, sectors or resources at risk, and the threats posed by the reduction or loss of such resources, thus being able to mitigate or adapt to that risk (IPCC, 2007). Our study aims to analyse vulnerability and adaptive capacity to changing climate conditions in the viticulture sector, based on a case study among wine producers of *El Penedès* region, Catalonia. In doing so, the study draws on a vulnerability assessment framework to examine how individuals and social actors in this sector experience and manage climate risks, and to identify the factors that facilitate or constrain such management (Belliveau *et al.*, 2006). We account for differentiated capabilities and contexts, from farms assets to farmer-market interactions, acknowledging that climate variability and change may not be the most important source of stress that makes farmers more vulnerable or that triggers adaptation actions.

2. Research context

2.1. Climate change, agriculture and adaptation

Climate change is regarded as one of the most important challenges that human civilization will face in the twenty-first century. The Intergovernmental Panel on Climate Change (IPCC) recently concluded that anthropogenic greenhouse gas emissions will continue to be the most prominent driver of climate change in the future, unless a radical departing from the use of fossil fuels in primary energy production is adopted worldwide (IPCC, 2007). Agriculture is one of the most important economic sectors that are likely to be affected by climate change, due to alterations in rainfall and temperature patterns, which will in turn affect seedling, growing and harvesting conditions.

Many studies have been carried out researching the likely impacts of climate change on agriculture (e.g. Fischer *et al.*, 2008; Rosenzweig & Hillel, 1998; Adams *et al.*, 1990; Morton 2007). Some of these suggest that crops would respond positively to higher CO_2 concentrations (e.g. Kimball *et al.*, 2002), increasing photosynthesis, biomass, and yield, among others. Nevertheless, associated impacts of climate change like high temperatures, altered patterns of precipitation and possibly increased frequency of extreme events such as drought and floods, may also probably combine to depress yields and increase production risks in many regions (Fischer *et al.*, 2005). Increases in temperature, for example, can affect the growing seasons, the rate of growth, the water transpiration and the cloud cover, among others (Rosenzweig & Hillel, 1998). Changes in these and other parameters can, in turn, bring about changes in agricultural production. Regions that where suitable for certain crops may become unsuitable, or crops may be able to be grown in areas where they never grew before (Rosenzweig & Hillel, 1998). Sea level rise can also become a threat to coastal agricultural land. This can lead to a reduction in the agricultural land available, in soil quality and in coastal habitats more generally. Fresh water may be insufficient, which can increase pressure on aquifers, and induce an uptake of salty water, leading to a reduced quality of underground water supply. As some regions become drier more irrigation may be needed to sustain crop production (ibid).

In spite of these actual and future risks, adaptation to environmental changing conditions is embedded in the practice and history of agriculture. Many studies can be found that either focus on how adaptation should take place (e.g. Smit & Skinner, 2002; Howden *et al.*, 2007) or assess how adaptation needs to be fostered in specific areas and for particular crops (e.g. Wang *et al.*, 2013; Reidsma *et al.*, 2010 & Chikozho, 2010). Smit and Skinner (2002), for example, classify and characterize agricultural adaptation options to climate change in Canada but they argue that their insights are relevant for other regions of the world. They describe four main adaptation strategies, namely technological developments; government programs and insurance; farm production practices and farm financial management; and other indirect strategies such as information and training that can stimulate the other three direct strategies. Their analysis suggests that adaptation options are mostly modifications to on-going farm practices and public policy decision-making processes with respect to a suite of changing climatic (including variability and extremes) and non-climatic conditions (political, economic and social).

2.2. Viticulture under a changing climate

The European Environment Information and Observation Network (2012) defines viticulture as the division of horticulture concerned with grape growing, studies of grape varieties, methods of culture, and related insect and disease control. In other words, viticulture is the science, production and study of grapes that deals with the series of events that occur in the vineyard. When the grapes are used for winemaking it is also known as viniculture.

Research on the impacts of climate change in viticulture has burgeoned over the last decade

(e.g. Schultz, 2000; Jones *et al.*, 2005; Webb *et al.*, 2007, Kenny & Harrison, 1992; Malheiro *et al.*, 2010; Jones & Webb, 2010; Battaglini *et al.*, 2009 and Mira de Orduña, 2010). Generally, it is thought that, due to the narrow niches for optimum quality and production of winegrapes, climatic conditions can affect this crop more than others. Vines' extraordinary sensitivity makes of them an early-warning system for problems that all food crops may confront as climate continues to change (Jones & Webb, 2010). The most important consequences of climate change on viticulture include advanced harvest times and temperatures, increased grape sugar concentrations that lead to high wine alcohol levels, lower acidities and the modification of aroma compounds. Under extremely hot temperatures, for example, vine metabolism may be inhibited leading to reduced metabolite accumulations, which may affect in turn wine aroma and colour. Musts with high sugar concentrations cause stress response in yeast, which leads to increased formation of fermentation co-products. Higher pH can lead to significant changes in microbial ecology of musts and wines and increase the risk of spoilage and organoleptic degradation (Mira de Orduña, 2010). From the industry's perspective, climate change can also add pressure on increasingly scarce water supplies, force growers to change the types of varieties they use, impose shifts in regional wine styles, and result in spatial changes within the viable grape growing regions (Jones & Webb, 2010).

2.2.1. Socioeconomic and cultural relevance

World wine production in 2011, excluding juice and musts, stood at 265 thousands of hectolitres. Wine production is lead by France, followed by Italy and Spain. The five largest European Union (EU) exporters (Spain, Italy, France, Portugal and Germany) account for 70% of the world's market. The importance of wine for these countries, however, is not only economic, but also cultural and historical. The history of wine spans thousands of years and it is closely intertwined with the history of civilisation and humanity itself. The earliest known wine production occurred in Georgia around 7000BCE, and some archaeological evidence shows that the domestication of grapevine took place in the Early Bronze Age (This *et al.*, 2006). Wine production and consumption was common in the ancient Greece and Rome, and both have divinities dedicated to its characteristics and effects. Due to the travels of the Phoenicians and Romans, vineyards extended all over the Mediterranean and cultivation techniques improved. Afterwards, in the Medieval Age, wine became part of the Christian tradition and it was also broadly consumed and produced (Estreicher, 2004).

2.2.2. Biophysical conditions and expected effects under climate change

Vineyards need soil and climate specific conditions to grow optimally. A good vineyard soil has more than 500 mm infiltration rate per day, more than 150 mm total available water in the root zone, more than 15% air-filled pore space and less than 1MPa penetration resistance at field capacity, which combined permit deep and spreading root growth and provide a steady, moderate supply of water (Jackson, 2008). A slight to moderate slope (5% to 10%) is desirable in vineyards as it accelerates the drainage of denser cold air from the vineyard, and an eastern exposure hastens the onset of photosynthesis and speeds drying of dew on the foliage and fruit (Kurtural, 2008). The desired range of organic matter is 2 to 3%, because it favours soil porosity, structure, nutrients and moisture. Moreover, ideal vineyard sites would have loam, sand loam or sand clay loam textures with a pH value between 6.0 and 6.8 to provide the optimum availability of nutrients (Kurtural, 2008).

Grapevine growth, fruit and wine production are thus affected by climate conditions in many ways. During winter, grapevines need some dormant chilling to effectively set the latent buds for the coming vintage. During the growing season, they need sustained average daily temperatures >10°C to initiate growth followed by sufficient heat accumulation to ripen fruits. The number of days whose average temperature exceeds this threshold is used to classify the wine growing regions within the Winkler Scale. Frost occurrence and timing are also significant for grapevines, which are favoured by low frost risk in spring and fall, and a long frost-free

season of 160 to 200 days or more (Ramos *et al.*, 2008; Kurtural, 2008). Finally, optimum temperature is around 20°C for flowering and fertilization, and higher (between 20 and 25°C) for grape maturation (Jackson, 2008).

The rise in global average temperatures projected for the next half-century may also bode problems for the wine industry. Jones *et al*. (2005) concluded that the impacts of climate change will not be uniform across all varieties and regions. They state that global wine production regions will have an average warming of 2 degrees Celsius ◦C over the next 50 years. This may bode problems to the regions producing high-quality grapes that operate at the margins of their climatic regions, becoming more difficult to have optimal ripening or balanced fruit. Nevertheless, some other regions may be pushed into more optimal climatic regimes for the production of current vine varieties. The impact of climate change in Mediterranean Europe has suggested short-term benefits in terms of more consistent and higher quality production, with lower year-to-year variability. However, the rise in global temperatures projected, particularly in growing seasons, can lead to shifts in varietal suitability (Jones *et al.*, 2005). Vines are generally not irrigated within this area, and changes in total rainfall or in its distribution throughout the year may have effects on water availability, particularly during the warmer periods of the year.

2.2.3. Adaptation in the viticulture sector

As a part of the agricultural sector, viticulture is also taking steps to adapt to climate change. Most of the literature focuses on regional adaptation and highlights the importance of both socio-economic and ecological perspectives (e.g. Belliveau *et al.*, 2006; Lereboullet *et al.*, 2013 & Bernetti *et al.*, 2012). Producers are vulnerable to conditions that not only affect crop yield, but also affect their ability to compete in or sell in markets (Bernetti *et al.*, 2006). Lereboullet *et al*. (2013) state that adaptation of agricultural systems to economic incentives with little account for climate change is unsustainable, while adaptation strategies designed for climate change with no regard for social and economic constraints at the farm level are also likely to be unsuccessful. Producers' ability to adapt or cope with multiple risks varies depending on factors as the availability of resources and technology, and access to government programmes (Belliveau *et al.*, 2012). In viticultural systems already at the edge of the climatic range for wine production, where competition is high and changes in cultural practices need long-term investments, climatic change could be particularly detrimental; it may challenge existing risk management strategies, which are efficient to deal with a naturally high inter-annual variability in climate but may proof insufficient to adapt to regular extreme conditions (Lereboullet *et al.*, 2013).

The extreme complexity of relationships and consequent behaviour of farmers is difficult to fully understand. To identify vulnerabilities of farming systems and to develop *ad hoc* adaptation policies, it is essential to comprehend the processes by which farmers adapt to climate change (Bernetti *et al.*, 2006). Lereboullet *et al.* (2013) compare the adaptation of the viticulture sector between Australia and France and find very specific responses for each country. In Australia, liberal regulations, weaker traditions and effective collective action have allowed for a more resilient viticulture system, with the implementation of a large scale recycled water irrigation system, and the possibility of altering grape varieties freely. In France, in contrast, producers' low average income and the poor economic health of the regional industry make long-term adaptation investments more complicated. Therefore, they conclude that actors at the business level (individuals or local group of producers) or at regional level (regional group of producers or regional organization) are key for building adaptive capacity, given that there is enough pressure on them to implement change. The understanding of climate change risk alone seems to be insufficient to trigger major adaptation decisions (Lereboullet *et al.*, 2013).

In spite of Lereboullet *et al*.'s (2013) view that pro-active adaptation is difficult to foster, reality

shows that adaptation is already on the agenda of multiple stakeholders in the viticulture sector. As an example, the Demeter project, which is a consortium of enterprises and wineries that study adaptation of the sector to climate change, is working toward the development of cost-effective adaptation options under different scenarios of water availability and temperature ranges (Proyecto Demeter, 2012). Another example could be the discussion of legal and cultural restrictions of Appelation d'Origine Côntrollée (AOC) systems in France, revising, for example, the possibility of cultivating different grape varieties in response to climate change (Metzger, 2011).

2.3. Research objective and questions

This study aims to analyse vulnerability patterns and adaptive capacity to changing climate conditions in the viticulture sector, based on a case study among wine producers of *El Penedès* area, Catalonia. In doing so, we account for differentiated capabilities and contexts, including livelihood and farms assets, as well as farmer-market interactions. We acknowledge that climate variability and change may only be one source of stress -and maybe not the most important- that makes farmers more vulnerable (i.e. poorer and/or more sensitive) to such stressors, or that triggers adaptation actions. The study is guided by a set of research questions, including:

- Which are the constitutive elements of vulnerability among wine producers?
- Are there differentiated adaptive capacities among wine producers and, if so, what key factors explain such adaptive capacity?
- Can we distinguish a variety of adaptive responses to climate variability? Are any of these responses different than those traditionally adopted in the past?
- What kind of policy interventions or market reforms can reduce vulnerabilities and enhance adaptive capacity?

The research aims to draw theoretical and empirical insights on vulnerability and adaptation in the viticulture sector and subsequently inform the development of sectorial policy in Catalonia. In doing so, the study also expects to draw relevant lessons for other agricultural sectors, as well as to discuss the implications of the research findings for the European Union and Spain's adaptation plans and strategies.

3. Conceptual framework

3.1. Understanding vulnerability

The concept of vulnerability has its roots in the natural hazards, food security and political ecology literature. It is defined by the International Panel on Climate Change (2001, p.995) as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and the variation to which a system is exposed, its sensitivity and its adaptive capacity". In the climate change field, vulnerability is generally viewed as a function of exposure, sensitivity and adaptive capacity (Yohe & Tol, 2002; Fraser *et al*., 2003). However, there is disagreement within the climate research community between two views of the term. On the one hand, as defined above, vulnerability can be understood in terms of amount of (potential) damage caused to a system by a particular climate-related event or hazard, depending on the physical hazards to which it is exposed, the frequency of occurrence, the extent of human exposure and the system's sensitivity to the impact of the hazard (Brooks, 2003). Brooks (2003) refers to this type of vulnerability as *biophysical vulnerability*, to emphasize the biological and social component of the properties of the system. On the other hand, vulnerability can be seen as the state that exists within a system before it encounters a hazard, as something that exists independently of external hazards (Brooks, 2003). Again, Brooks (2003) names this type as *social vulnerability* and it is determined by factors such as poverty, inequality or marginalisation.

When research is concerned with social vulnerability, the focus is then on understanding differentiated vulnerabilities, paying attention to poor members of societies, and taking into account multiple hazards at various geographical scales. Research results are normally measured in terms of physical or economic damage or human mortality or morbidity, hence social vulnerability can be understood as one of the determinants of biophysical vulnerability (Brooks, 2003). Biophysical vulnerability is conceptually linked to *outcome risk*, which also entails different interpretations within the scientific community. Outcome risk is understood as the probability of a disaster outcome, combining the probability of the hazard event with a consideration of its likely consequences. Both outcome risk and biophysical vulnerability are functions of hazard and social vulnerability. Therefore, what should be done is to assess vulnerability as a part of the risk chain, understanding that altering vulnerability is one risk-management effective strategy (Ibid).

Timescale is also relevant in vulnerability assessments, with the possibility to distinguish between current and potential vulnerability. Current vulnerability is determined by past adaptation and current availability of coping options. On the other hand, potential vulnerability aims to explain the specific point in the future to a specific hazard as a result of realizing all its current adaptive capacity through anticipatory adaptation. Therefore, current vulnerability provides a snapshot that may be useful to analyse an event that occurred immediately, while potential vulnerability projects the event to the future taking into account the likely adaptation conducted (Brooks, 2003).

Assessing vulnerability is important as it enables the identification of people, sectors or resources at risk, and the threats posed by the reduction or loss of such resources, thus being able to mitigate or adapt to that risk (IPCC, 2007). For example, the vulnerability of agriculture to climate change depends on many different aspects, which can be classified as social, economic and environmental factors. Globally, climate change entails the prevalence of environmental constraints to crop agriculture, climate variability and the variability of rain-fed cereal production, including changes in potential agricultural land, changes in crop-production patterns, and the impact of climate change on cereal-production potential. The ability of agriculture to adapt to and cope with climate change depends on factors such as population growth, poverty and hunger, arable-land and water resources, farming technology and access to

inputs, crop varieties adapted to local conditions, access to knowledge, infrastructure, agricultural extension services, marketing and storage systems, rural financial markets, and economic status and wealth (Fischer *et al.*, 2002). Narrowing the scope, Morton (2007) focuses on smallholder agriculture, highlighting the importance of market access, but also the importance of other factors, such as diversification, family labour, and traditional knowledge. Also at a local level, Eakin (2005) concludes that local vulnerability consists of understanding how farmers account for risk in decision making, as well as identifying the exogenous factors that may affect a households' livelihood security and how they interact to amplify or mitigate risky outcomes.

3.2. Understanding adaptation and adaptive capacity

Human societies have adapted during history in order to cope or manage changing conditions, stress, hazards, risks or opportunities. The term adaptation itself comes from natural sciences, specially evolutionary biology, understanding it as the development of genetic or behavioural characteristics that enable organisms or systems to cope with environmental changes in order to survive and reproduce (Smit *et al.*, 2006). Eventually the term was used on human systems, as the process by which groups of people add new and improved methods of coping with the environment to their cultural repertoire (O'Brien *et al.*, 1992). In more recent social science work, cultures that are able to respond or cope with change are considered to have high adaptability or capacity to adapt (Denevan, 1983). The use of the term in climate change research refers to "the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2007, p.869). It can be classified in many ways: by timing relative to stimulus (anticipatory, concurrent, reactive), intent (autonomous, planned), spatial scope (local, widespread) and form (technological, behavioural, financial, institutional, informational) (Smit *et al.*, 2000).

Adaptive capacity is thus the ability or potential of a system to respond successfully to climate variability and change, and includes adjustments in both behaviour and in resources and technologies (IPCC, 2007). It includes the capacity to modify the exposure to risk and to absorb and recover from losses, and the ability to exploit new opportunities (Vincent, 2007). Adaptation can thus be seen as the realisation of adaptive capacity; it is the result of the combination of resources and assets that adaptive capacity represents, which leads to actions and investments of adaptation (Adger *et al.*, 2005; Smit *et al.*, 2006). Adaptive capacity represents potential rather than actual adaptation. Hence high levels of adaptive capacity will reduce a system's vulnerability to hazards in the future or to hazards that involve slow change over relatively long periods, to which the system can adapt reactively. Existing adaptations resulting from past adaptive capacity determine current levels of vulnerability (Brooks, 2003).

As for vulnerability, adaptive capacity can be analysed at different scales. Some scholars have focused on the national scale, in order to assess international decision-making, e.g. investments in adaptation derived from the UNFCCC. Yohe and Tol (2002) develop adaptive capacity indicators at national level, suggesting eight different determinants that can be used worldwide. Nevertheless, one of their conclusions is that many of the variables are not possible to quantify, and need to be described qualitatively. Brooks and colleagues (2005) develop an index to assess climate-related mortality at national level and conclude that locally specific ones must complement national-level indexes. The latter can be controversial as they simplify reality and thus run the risk of inaccurately representing the desired reality (Vincent, 2007). A local-scale approach shows analytical advantages and disadvantages. As an advantage, for example, local governments can use local indexes to develop policies since many decisions are taken at sub-national levels, and NGOs and individuals can use such indices to suggest actions and steer responsive behaviours. The main disadvantage of this approach is the fact that local indexes are completely context specific and they cannot be easily extrapolated at other places or over time (Smit *et al.*, 2006).

Brooks (2003) introduces a conceptual framework that encompasses the concepts of vulnerability, risk and adaptation. He argues that the factors that determine whether or not adaptation occurs operate at different scales depend on how the system under analysis is defined. He argues that systems are not closed, and that by focusing only at one scale we may not be considering important obstacles to our adaptation process that are outside the system defined. Therefore, he suggests that, in order to facilitate adaptation, one must address processes operating at the sub-system scale, as well as the wider social, economic and environmental context within which the system is embedded. Furthermore, Brooks criticizes the idea that adaptive capacity is something inherent in a system, as such is likely to lead to an emphasis on processes operating at the system and sub-scale, and to neglect larger-scale processes that produce vulnerabilities and constrain adaptive capacity; an idea that somehow will be convenient for certain ideologically-based groups and institutions (Brooks, 2003).

Despite scale controversies, understanding adaptive capacity is considered a prerequisite for targeting interventions to reduce the adverse impacts of climate change. In order to do so, indicators and index are commonly used (Vincent, 2007; Adger *et al.*, 2005; Yohe *et al.*, 2002; Brooks *et al.*, 2005). Vincent (2007), for example, elaborates two indexes, one at national level and another at household level in order to map the adaptive capacity of African countries and South African households. She argues that the driving forces at these two different scales are similar, but that it is meaningless to transfer one index across scales, because the indicators needed to adequately capture the driving forces are highly dependent on scale. Hence, different indices are needed for national and local levels. The fact that they are scale-specific is one of the most typical uncertainties that indexes face. Yet some other uncertainties can be distinguished in the index-defining process: the choosing of driving forces, since they are mostly based on assumptions; the indicators selected to represent each force, which have to accurately capture the variable in question; the direction of the relationship between the indicator and adaptive capacity, and the impossibility of precisely project change in adaptive capacity over time (Vincent, 2007).

Timescale is also a recurrent source of controversy in adaptive capacity research. Indicators only provide a snapshot in time of a potential state that is dynamic and multidimensional, being embedded in a variety of different processes (Adger *et al.*, 2005). Indicators are actually mapping the present adaptive capacity, while what is thought to assess is a likely future under climate change conditions. This duality between present and future is seen in different ways: Adger and Kelly (1999) suggest that this is appropriate to identify the means of increasing adaptive capacity. Moss *et al*. (2000) propose the use of socio-economic scenarios to show the likely changes of adaptive capacity over time, even if this results in making mapping more complex and uncertain. Another source of uncertainty is the fact that there is no way of validating the effectiveness of indicators. The most common method is testing the correlation with past data, which is less than ideal (Adger *et al.*, 2005).

3.3. Vulnerability and adaptive capacity in vine sector

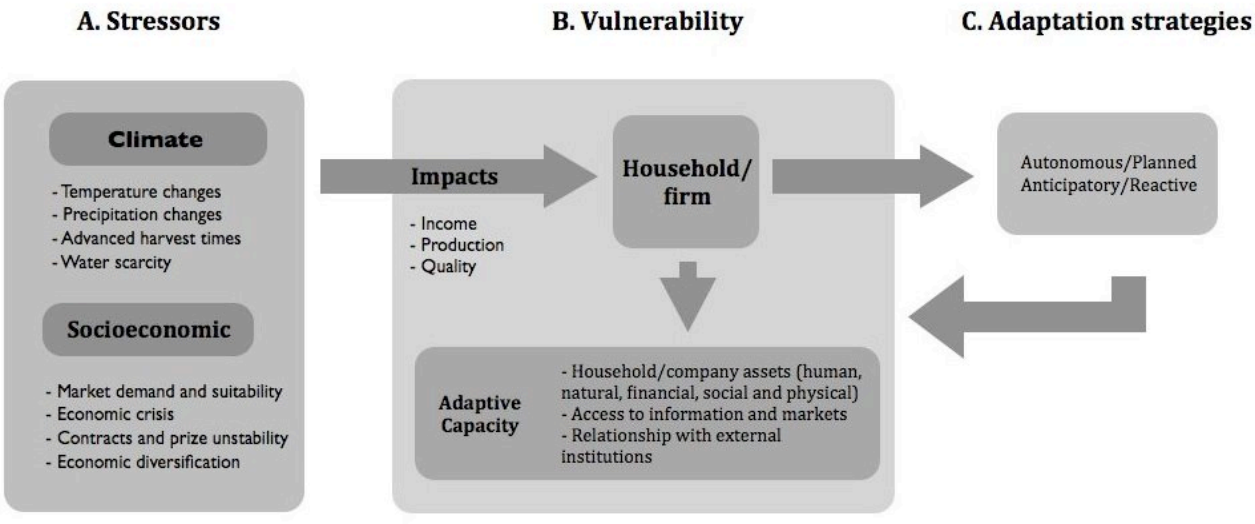
As a part of the agricultural sector, vulnerability and adaptive capacity of viticulture are already being studied and occurring. Most of the studies focus in its adaptation, such as Lereboullet *et al.* (2013), who compare the adaptation of the Australian and French viticulture sector from a socio-ecological point of view, or Bernetti *et al.* (2012) who study the impact of climate change on the economy of the Tuscan vine sector and the likely adaptation strategies, or Diffenbaugh *et al.* (2011) who prove the necessity and advantages of taking steps to better adaptation in the same area. Vulnerability is also being assessed, as Belliveau and colleagues (2006), who study the multiple exposure and dynamism of vulnerability in the grape industry of Canada. It has to be stressed that all studies include both socioeconomic and biophysical approaches to vulnerability and adaptive capacity, pointing to the need of analysing multiple exposures. These several interactions shape decisions and management practises, allowing many different

responses depending on the combination of the different stressors and circumstances of the concrete system. To analyse this complex framework, system-based vulnerability assessments have emerged as a complement to traditional scenario-based approaches. They draw on past and current experiences to understand how particular groups experience and manage climate risks; to identify the factors that facilitate or constrain management; and to assess the prospects for improving it, especially in the light of anticipated future risks (Belliveau *et al.*, 2006). Therefore, the purpose of this study is not quantifying or ranking vulnerability, but understanding its foundations based on the stakeholders' experience. The concept of multi-scale factors influencing a system is found in the scholarship on agricultural decision-making. The farm is generally considered the main decision-making unit, composed by labour, land and capital that are connected through day-to-day management practices. It is viewed as a dynamic system that operates within and changes in response to external but interconnected systems (Belliveau *et al.*, 2006).

In this research, the system studied is also the "vineyard farm" as a decision-making unit, which includes the land, the planted crops, and the household/firm capitals (e.g. social, technological, human, financial, natural), all related to each other through daily and regular interactions. Vulnerability is in turn conceived from a social perspective; farmers' vulnerability is influenced by the impact of different stressors and the adaptive capacity of the system. Such adaptive capacity is in turn shaped by additional factors and conditions that are either intrinsic or extrinsic to the "vineyard farm", including the household/firm capitals themselves, access to information, markets and other peripheral institutions.

Figure 1 illustrates our system of reference, which includes the socio-ecological "vineyard farm" system (Box B) and the dynamic stressors that may affect such system, including climate conditions and socioeconomic pressures (Box A). As noted above, the "vineyard-farm" system has an inherent adaptive capacity, which combined with the stressors, results in a "dynamic" state of vulnerability. Stressors can affect the household/firm assets, the cropping system or the quality of the products derived from the latter. Vulnerability may simultaneously increase or decrease depending on the adaptation strategies deployed by the household/firm (Box C), which can include autonomous or planned actions (i.e. purposefulness adaptation), and anticipatory or reactive (i.e. the timing in relation to the stressor). The following section introduces the case study region, the research stakeholders and the methods.

Figure 1. Conceptual model linking vulnerability and adaptive capacity in the viticulture sector



Source: own elaboration

4. Case study and methods

4.1. El Penedès region, Catalonia

This study explores the vulnerability and adaptive capacity to climate change among wine producers of *El Penedès* region, Catalonia, north-east of Spain. Catalonia is one of the leading exporting regions of Spain. Its exports have the highest financial market value in Spain, i.e. 489 million Euros in 2009 (OEMV, 2009). Catalonia's wine production is the second most important in volume of Spain after the region of La Rioja, with a total of 205 million litres in 2011. Taking into account such figures then, Catalonia is one of the most important regions for wine production globally. The region counts with 61,391 hectares of vineyards (i.e. 7.7% of the region's cultivated land) and of which 44% are located in the central area of *El Penedès* (Idescat, 2009).

The history of vineyards in *El Penedès* dates back to the VII century B.C., when Phoenicians brought their wine culture into these lands. Since then, vineyards have shaped and changed the way people related to each other and the region's landscapes, resulting in deforestation, terraces, and new communication infrastructure to connect farmhouses and vineyards. Penedès is also a Denomination of Origin (DO), i.e. the Spanish labelling system for the EU Protected Designation of Origin, which promotes and protects names of agricultural products and foodstuffs (European Commission, 2012). The DO is made up of three distinct productive areas: 1) *Penedès Superior*, near the inland mountain range; 2) *Penedès Marítim*, between the sea and the coastal hills, and 3) *Penedès Central*, on the plain between both areas. Its climate structure is strongly Mediterranean, with hot and dry summers. The annual average temperature is 18°C (7 to 23°C) and annual average rainfall of 500 mm, which can be of around 800 mm in the mountainous areas (DOP, 2012). Up to 3.750 farmers work in the area, cultivating approximately 23,500 ha of vineyards (Andana, 2012). In total, around 156 cellars can be found (DOP, 2012).

4.1.1 Biophysical conditions and expected effects under climate change

In Catalonia, according to the First Report on Regionalised Climate Scenarios for Catalonia (2011), warmer and drier conditions are expected at the end of this century. These include an increase in air temperature of 3°C at 2m high in 2100, a minimum 15% decrease in precipitation and a 15% decrease of wind speed at 10m high. However, impacts can diverge regionally. Ramos and Martínez-Casanovas (2006) study suggests that significant changes due to climate change can already be felt and observed in *El Penedès* region. With an 80-years dataset (1920-2000), they find no change on annual precipitation but significant increases in maximum precipitation recorded in single events (1 day) or short periods (5 days). Changes in rainfall distribution have already had negative effects on water availability for crops and contributed to accelerate erosion processes. In the future, these changes may result into further water stress on growth and impact the ability of grapevines to undergo normal ripening (ibid.). Dividing precipitation into stages of vine development, the authors' projections show a critical decrease of rainfall between May and June, from vineyards' bloom to veraison[1]. As a result, moisture stress could disrupt rapid cell division and result in significant dehydration and sunburn, which in combination can reduce berry size and yields (Peacock, 2005).

Ramos and colleagues (2008) also show an average growing season warming of 0.04°C per year in *El Penedès* area during 1952-2006 and describe an advancement of 3 to 7 days per 1°C warming during the growing season over the period 1996-2007 for the 3 main varieties present in the region – Macabeu, Parellada and Xarel·lo. These changes may be already impacting negatively on both wine production and quality (Webb *et al*., 2007), and leading to a volume

[1] Change of colour of the grape berries. It represents the transition from grape growth to ripening, and many changes in their development occur at veraison.

loss from a combination of heat and lack of water, which can make sugar and alcohol concentration increase (Mullins *et al*., 1992). Ramos *et al*. (2008) also found significant changes on maximum temperatures during the period 1952-2006, showing an increase in the number of days with temperatures >95th percentile. Extremes during growth of the berries induce stress, premature veraison, berry abscission, enzyme activation, and cause less flavour development (Coombe, 1987; Mullins *et al*., 1992). Significant decline has also been found in the number of moderately extreme cold days (Tmax < 10th percentile) and moderately extreme cold nights (Tmin < 10th percentile), and significant increase in moderately extreme warm days and nights (Tmax and Tmin > 90th percentile). This can negatively affect the dormant chilling that grapevines need and can also lead to a warmer growing season which result in earlier phenological events, higher wine quality with higher ripening diurnal temperature ranges, and reduced production in the warmest vintages (Ramos *et al.*, 2008). Moreover, Ramos *et al.* (2008) suggest that water demand may increase between 6 and 14% per 1°C warming in the growing season (i.e. April to October). Predictions for Winkler Scale[2] show an increase from 155 to 427 units, which suggests a shift in classification of regions from those suited to early and mid-season table wine varieties for high production, and good to standard quality wines (III), to those where table wine quality will be acceptable at best (IV) (Ramos *et al.*, 2008). These trends in temperature and rainfall in State II may alter the nature of wine production in *El Penedès* as it is known today. This in turn justifies why climate mitigation and adaptation processes need to be fostered to reduce the vulnerability of producers and the overall sector to climate change impacts.

4.1.2 Identifying and selecting actors

This research differentiates between different types of actors in viticulture, in order to account for different production profiles and capacity to resist stressors and adapt to risks (Table 1). In *El Penedès*, and in the past, every family produced its own wine for their own consumption, or they used to sell it in Barcelona, Catalonia's capital city. At present, however, most growers bring grapes to wineries that produce the wine. Large transforming companies have huge extensions of vineyards, which they have been acquiring from these ancient small wineries, and they also buy grapes of small producers. Therefore, during recent years, crops are being owned by less but more professionalised owners. This tendency is a perception of most of the actors analysed, but it can also be proved by looking at the agrarian surface used (SAU). Between 1999 and 2007 the number of agricultural holdings decreased by 17,5%, while the farmland increased slightly by 1,1%. This represents an average increase of 23,4% of the farmland used per farm unit by any type of crop. This confirms the tendency of agrarian exploitations becoming bigger to be more competitive (Idescat, 2010).

Medium wineries are also important in *El Penedès*. They produce less bottles, have fewer hectares and they also buy from small growers. They are thus able to produce less wine. Due to the ongoing process of land concentration, the number of farmers who produce their own wine has steadily decreased over the last 30 years. Nevertheless, there are still grape growers who make their own wine, often seeking added value to their product. These are the small wineries.

[2] Technique for classifying the climate of wine growing regions, based on the hypothesis that grapevines do not grow if the temperature is below 10 °C. The number of days during the growing season (1st April – 31st July) which its average temperature exceeds this threshold classifies regions according their suitability to produce quality wines (from I to V).

Table 1. Stakeholder's typology and associated characteristics

Group	Stakeholder's name	Acronym used in the text	Characteristics
1	**Large winery**	LW	Complete production cycle More than 1 million bottles
	Middle winery	MW	Complete production cycle Between 200.000 and 1 million bottles
	Small winery	SW	Complete production cycle Less than 200.000 bottles
	Intermediary	I	Partial production cycle: transform grapes to sell to companies
	Cavist	C	Partial production cycle: buys wine and produces cava Does not own crops
2	**Grower**	G	Partial production cycle: grapes production Has no other occupation apart from vine
	Diversified grower	DG	Partial production cycle: grapes production Has other crops a part from vine
	Partial dedication grower	PDG	Partial production cycle: grapes production Has another occupation apart from vine

Partial dedication to vine in *El Penedès* region is also perceived to be decreasing by different stakeholders. There used to be producers who worked both in viticulture and in non-agricultural activities but it seems that new generations have abandoned this tradition and have sold lands to Larger companies or abandoned them all together, deepening the land-concentration phenomenon. Intermediaries are also naturally found in the viticulture sector. They buy producers' grapes at a low price, making wine out of them, and sell this wine afterwards to other companies that use it to make more wine or cava. Finally, the cavist is a very common actor in *El Penedès*: they buy wine to different companies to make their own cava afterwards. Normally they do not own vineyards, but buy to intermediaries.

The actual relationship between growers and wineries can be quite controversial. Wineries depend on market prices and demands. Therefore, from one year to another, they can decide if they buy or not a grower's grapes, particularly if the latter do not fit certain properties or because market demand has changed. Long-term contracts between these two actors are uncommon, which has in turn created a hierarchy between growers, differentiating between the ones who can sell their grapes easily and at a good price, and the ones who undersell them.

4.2. Research approach and ethics

This research relies on a bottom-up vulnerability approach that aims to understand differentiated capacities and responses to climatic and other stressors among viticulture actors in *El Penedès* region. A non-exhaustive review of grey literature and academic research on vulnerability and adaptation in the agriculture and wine sector was undertaken to situate and frame the research. Subsequently two key informants from the Catalan Wine Institute and an experienced worker of

El Penedès wine industry were interviewed and provided contact details on a number of relevant actors in the region. A total number of 15 actors were interviewed, ensuring that each of the categories highlighted above was represented. The size of the sample is a main caveat of the study, and results should thus be treated with caution.

The interview was designed following the Sustainable Livelihoods Framework (SLF) (DFID, 1999) (Annex A). It was divided in five main sections coinciding with the five types of capitals identified by the SLF (i.e. human, natural, financial, physical and social) and three additional sections related with climate and socioeconomic stressors, adaptation practices and diversity of crops and income. Such design was based on Eakin and Bojórquez-Tapia's study (2007) of household vulnerability in Mexico, combined with knowledge gained through the key interviewees. Livelihood/firm adaptation strategies are qualitatively evaluated in relation not only to the household/firm's sensitivity to climate impacts such as water availability or changes in temperature, but also in terms of economic stability (e.g., sells, machinery owning, access to loans or subsidies) and the farmers' own understandings of climatic risks and coping strategies.

Interviews were carried out separately and personally and were recorded with the consent of the interviewee (read below). All interviews were transcribed and interpreted, distinguishing across actor categories (Annex B). Due to the limited sample size, data analysis brought together all the different types of growers in one single category (i.e. growers), regardless of their labour dedication or degree of diversification. However, when relevant differences were identifed, they were noted and discussed separately. Wineries were also grouped regardless of size, and intermediaries were considered separately. Cavists were generally considered wineries, since they also produce wine or cava, and have similar processes and stressors than wineries. However, due to the fact that they do not have crops, sometimes they required a separate analysis and discussion, as noted in the results section. Data derived from the interviews was also complemented from data obtained from institutions like the Penedès Viticulturists Association or *La semana vitivinícola* magazine.

Research ethics principles have been followed over the course of this research. Informed consent has been asked before each interview, and participants have been informed on the purpose of the project, their right to decide whether or not to respond to any given question, and the way in which data was going to be analysed, stored, anonymised and treated confidentially. In this regard, interviewees' personal data, such as contact details with names, telephones, address, has been stored safely in the author's computer and will be deleted two years after the end of this project, in order to facilitate contact if required in the near future. The information has not been made available to any other individual or organisation.

5. Results

5.1. Characterising actors in the vineyard-farming system

5.1.1. Age and history

The average age of interviewees involved in the vineyard-farming system is between 40 and 45 years old, nearly all male, with the oldest two (65 and 69 years old, respectively) belonging the winery group. Higher education levels are found in the winery group too, with 7 out of 10 holding degrees in engineering or other technical background. In contrast, educated people in the growers' group were only one out of five. The rest of interviewees had coursed secondary school or engaged in professional training studies (see Annex B).

Data related with the history of wineries and growers is quite similar among groups. Around three out of ten wineries have a history that dates back to the beginning of the last century, and many generations of the same family have been involved in managing the winery and its vineyards. The same for the growers: three out of five have cultivated grapes since they were children, their families had managed the vineyard-farming system for generations and they had inherited land from parents and/or grandparents. In fact 100% of the interviewees confirms that their family was also involved in the wine sector, which shows the extent to which the vineyard-farming system and the related industry is based on family tradition. Moreover, 13 out of 15 interviewees explain that family members, both young and older, still participate in farming or business-related activities.

5.1.2. Land, crop diversity and water

When mapping vulnerability of the vineyard-farming system it is important to understand what natural resources people have access to and what influences their decisions regarding what to use. For such purpose, the land owned or rented and the typology of the crops grown were analysed. In the specific context of smallholder farm households, crop diversity has been shown to be strongly associated to household's capacity to manage environmental and market risks (Eakin, 2005; Eakin & Borjórquez-Tapia, 2007).

Interviewees logically diverge on the amount of land owned or managed under the vineyard-farming system (Table 2). Overall, large wineries are the ones who own more land, followed by medium and ending with small ones. This trend may be linked to the economic facilities of each group, or the access to credit and other economic assets. Generally speaking, the more hectares you own, the larger the production. For example, SW3 has 40 ha and produces 100.000 bottles/year, and MW2 has 50 ha and produces 250.000 bottles/year. Other interviewees produce wine beyond their cultivation capacity. MW1, for instance, produces 1 million bottles with only 80 hectares owned. This can be explained stating that some wineries also buy grapes to growers. Specifically, MW1 buys the production of other growers who control approximately 70 hectares. As MW1 stated, this is an strategy to mitigate market risks: "Only 50% to 70% of our production comes from vineyards; if there is a market crash we can still sell our product and avoid buying to other growers". However, the reverse has also been found: SW1 produces less than other producers (i.e. 60.000 bottles/year) but owns 80 hectares. This is explained by the fact that they only choose the better grapes to produce high quality wines.

Table 2. Wineries typology and their hectares owned, extra grapes bought and production

Code	Hectares owned	Grapes bought	Production (bottles/year)
BW1	-	-	70.556.800
MW1	80Ha	Yes(60-70Ha)	1.000.000
MW2	50Ha	No	250.000
SW1	77Ha	No	60.000
SW2	6Ha	Yes	40.000
SW3	40Ha	No	100.000

Four out of five growers rent land to other owners while none of the wineries do. This is so because they need larger extensions of land to live off their produce. More extension often translates into more production, potentially higher diversification (e.g. cultivating vineyards, as well as other crops) and generates employment. As PDG1 explains: "with the crisis people has more availability to work, so I rented more land this year with some partners to employ more people". Furthermore, sharecropping is a common arrangement in *El Penedès*: growers rent land and gain the right over three to four fifths of the additional production, thereby increasing production volume and gaining and extra income. This is the case of DG3, for example.

Table 3. Growers typology and their hectares owned and rented

Code	Ha owned	Ha rented
DG1	5Ha	1Ha
DG2	26Ha	0Ha
DG3	0Ha	115Ha
PDG1	2,5Ha	5,5Ha
G1	15Ha	

Crops' diversity show the dependence on a concrete crop type. Growers and wineries present opposite situations. Nine out of ten wineries only have vineyards (taking into account that cavists do not own crops), while four out of five growers diversify the crops grown. They have orchard, fruit trees or cereals a part from the vineyards. Most of the growers argue that diversifying is a way of ensuring income and not depending that much on grape prices. As PDG1 emphasizes "vine is a long-term investment, and without having a fix contract (e.g. if the land is rented) it is a difficult decision to grow it. Besides, you need to ask for planting rights[3] and also to be sure that you will be able to commercialize the product". Some stakeholders have other uses on their land. For example, and in contrast with most growers, wineries own forests in the region.

Concerning water resources, 11 out of 15 interviewees, both wineries and growers, do not irrigate their crops. Vineyards are normally rain fed or count with a small watering support infrastructure that consists of water taken out from wells and distributed through a drip system. Some (e.g. PDG1, DG3) argue that they do not irrigate because of regional water scarcity but they think it may become necessary in certain periods, especially if climate change brings less rainwater or longer dry periods. In contrast, others like SW2 do not like watering crops for productive reasons: "I do not irrigate because I am not interested in high big productivity but in good wine instead", or MW2 who argues that "if you water vines every year, wine will always have the same flavour". It seems that irrigation has no sense when specific and great quality

[3] Planting rights are a methodology of the Catalan regional government to control the number of vineyards planted. Growers have planting rights on the hectares they own. If more terrain wants to be cultivated, planting rights need to be bought to other owners who do not use them or participate in the public tender offered by the government.

flavours are sought. These opposed strategies show different perceptions and reactions to possible future climate risks and related water stress.

Growers have mostly adopted agri-environmental production practices. Four out of five follow these measures, and half of them on all their crops. These practises consist on cultivating without chemicals addition, only with organic fertilizers and only using natural phytosanitaries. Growers argue that they do so because they believe in such practices, but also because grapes are easier to sell and better paid. In the case of wineries, the adoption of agri-environmental practices depends on the type of firm. Medium and small wineries state that 100% of their production follows agri-environmental criteria, and have the official certificate. In contrast, none of the cavists followed any measure, which is logical since they do not own crops.

5.1.3. Labour

I turn now to analyse the amount of labour utilized by the interviewees to run the vineyard-farming system over the year. Differences between large and medium wineries and growers can be observed (Table 4). Similar labour requirements can be found between small wineries and growers. They both have very few permanent employees and, in general, hire very few people in busiest times. Small wineries generally cannot afford to pay many employees and cover that work being helped by relatives or friends. Seven out of eight growers and small wineries confirmed that family participates in the vineyard-farming system activities. Large and medium wineries have the largest amount of employees. Some of these companies contract extra workers in the busiest days of the year, but no strict trend has been found in this regard. Cavists employ fewer people and contract less during the busiest periods. Since they do not have vineyards, they do not need to employ people in field-based agricultural activities, e.g. pruning and harvesting.

Table 4. Wineries and growers typology and their employees

Code	Number of employees	Number of employees in busiest time
BW1	450	-
MW1	23	46
MW2	25	0
SW1	6	19
SW2	2	0
SW3	2	5
I1	20	40
C1	2	0
C2	0	6
C3	6	0
DG1	2-6	0
DG2	2	Not verified*
DG3	3	0
PDG1	3-6	7-8
G1	2	7

*D.G.2 hires a company to harvest or defoliate, so the number of employees depends on it

5.1.4. Financial and technical assets

Financial capital, including regular income and other economic assets, is key to ensure the viability of the vineyard-farm system. In this study, the diversity of income sources can inform us about the farmer or the firm's ability to manage risks. Ten out of fifteen growers and wineries

have the vineyard system as the sole source of income whilst cavists are more diversified and have other jobs or activities. However, such activities only represented a low share of the overall income.

Product placement by the interviewees is diverse, and they often combine export activities with local sales at varying degrees. For example, MW1 exports on average 82% of its production, whereas MW2 only exports around 10%. Growers' sale strategy also varies. As DG1 says "I sell grapes where I can" and he argues that "black grapes are easier to sell to middle wineries, but there is a lot of white grape in Penedès, so that type is more difficult to sell". All growers sell to cooperatives or cellars in the surrounding areas, and complain about the lack of long-term selling contracts, the low prices and the difficulty of searching for a buyer depending on the year.

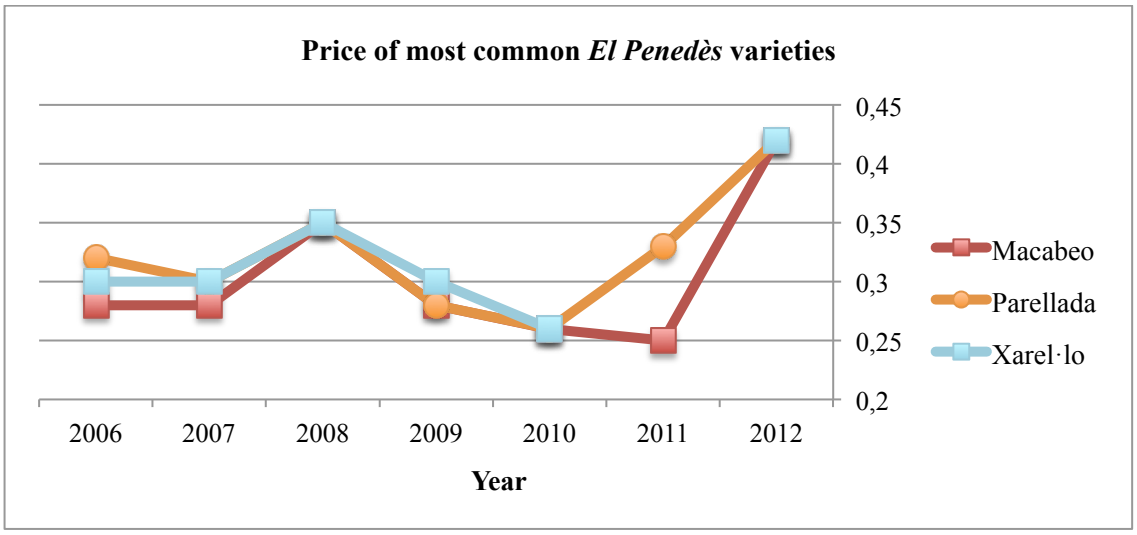
Current economic crisis may be seen as one of the most important problems affecting income in the vine sector. Growers consider being permanently in crisis, due to factors as the lack of fix contracts and low prices, so they do not especially notice the current one. By contrary, wineries are more sensitive. Mostly they have a decrease on sells, and some tried to solve it rising exports to other countries.

Concerning market and fluctuating prices only half of the wineries think that selling prices are inadequate. Wineries argue that prices are decided by market and offer-demand reasons, or state that producing wine adds value to the product, allowing it to be proportionally more expensive than grapes. By contrary, all growers considerate prices inappropriate, low and a reason for not appreciating their work. In this regard, DG2 notes that "Price is always very low, decided by the monopoly of big companies, and the administration does not want to interfere. Sometimes it is not even enough for living". G1 adds that "The main problem is that when you harvest you do not know the price, or the demand that the company you are selling has".

Data of grape prices was consulted from La Semana Vitivinícola (2012). Their database includes the prices of all Penedès varieties from 2006 to 2012 depending on their alcohol degree. For the most common *El Penedès* varieties (Figure 2), which are Xarel·lo, Macabeo and Parellada, prices raised slightly in 2008, then lowered to the cheapest price in 2011, and increased again significantly in 2012. The variation among the three varieties is practically the same. Concerning French varieties (Figure 3), price fluctuation is more irregular. However, a small rising in 2008 can be seen (especially in Merlot and Cavernet-Sauvignon), followed by the price decrease of 2011 and the final rise of 2012. When asked about such a rise, the interviewees noted that it was due to a smaller global harvest. With a better harvest in the coming years, prices could lower again.

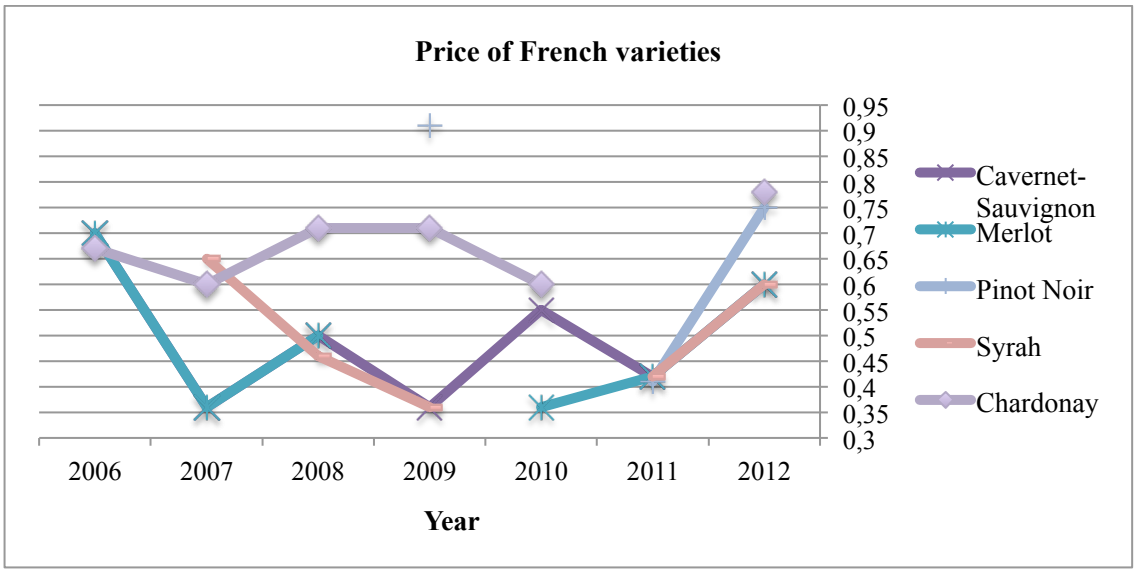
Comparing both figures, it has to be pointed that *El Penedès* varieties always have lower prices than French ones. Even with the rising of 2012, local varieties are sold for around 0,4€/Kg, while French varieties sale for approximately 0,7€/Kg. It seems that local varieties are being contempt or underestimated, maybe due to larger production levels in the Penedès region, which translates into more offer and increased competition.

Figure 2. Price variation of the most common *El Penedès* varieties during 2006-2012 period.



Data Source: La Semana vitivinícola. Own elaboration.

Figure 3. Price variation of the French varieties during 2006-2012 period.



Data Source: La Semana vitivinícola. Own elaboration.

Most interviewees have access to subsidies, loans and insurance to varying degrees. All growers interviewed received a subsidy, some for agro-environmental procedures, and others for being young farmers or for renewing parts of the vine. Most of them also asked for bank loans, mostly to buy machinery needed. One common characteristic is that they "only ask for a loan if I know that I can pay it back" (DG2). Regarding wineries, half of them asked for an agri-environmental program subsidy, except cavists who do not own crops. Bank loans in wineries are mostly used to renovate the cellar or to buy new machinery. All growers and small wineries interviewed also have hailing and frost insurance on vine. Some of the larger wineries also insure crops, and have other insurance products for the cellar and other assets. Interviewees are generally conscious about the importance that insurance as a financial instrument may have in the future. As PDG1 states, "Insurances contemplate droughts or extreme weather, which can be useful in future climate conditions. They are adding new options and broadening them every year."

Owning machinery is a way of ensuring the ability of pursuing particular livelihood strategies and not depending on others. However, none of the growers interviewed own all of the necessary equipment to maintain their crops, but rent some. Normally, what is rent is not the machine itself, but a services company that undertakes the required work. Machines for pruning and defoliating are the most commonly rented. Concerning wineries, half of them own all the machines, specially middle and large wineries. The most commonly rented ones are bottling chains, especially by small wineries.

5.1.5. Social capital and knowledge

Social capital encompasses the resources that people draw in pursuit of their livelihood objectives, including social networks and membership of formalized groups. It helps to shape vulnerability since these networks enable people to cope with stocks and change. Membership to farm organizations is thought to be a key indicator of social capital. Five out of eight wineries participate in farm organizations, while in farmers is only two out of five who do so. The types of association are also different. Farmers participate in agricultural unions, or plant protection groups, whilst wineries are part of institutions as the Catalan Winemakers Association, the Winemakers Penedès Union and other institutes. In comparison, wineries participate more than growers. However, when asked to the growers, they consider being united and organized very important to achieve better conditions and prices for their jobs, which is not demonstrated by engaging in organisations in our data. Some of the growers also refer to the individualism of the farming life and the difficulty of trusting other growers or their organisations as an excuse for not being organised.

To gain knowledge about coming climate events or analyse weather conditions, stakeholders check different weather and pest-advice websites on Internet, or have small weather stations with water-collecting systems. The only groups who do not are cavists, because they do not need to check weather, since they do not have crops. By contrary, knowledge related with techniques have an opposite trend, showing how growers do ask for technical support, while the majority of wineries do not, arguing that they did an effort of self-formation or have their own technicians. Farmers are regularly visited by companies they want to sell the grapes to. These technicians tell growers when fruit is at the exact harvesting point. A part from that, some participate in plant protection groups, who are experts in plague detection and farmer assistance.

All interviewees consider to be taking into account ancient knowledge when managing the vineyard-farm system. Nine out of fifteen make part or all process by hand. Others check the moon cycle before planting or harvesting, recover ancient grape varieties or use the properties of other plants to avoid plagues. Same pruning, plowing and weeding practises are implemented to regulate the characteristics of the grapes or their access to water, or some cellar techniques are still the same that were used by older family members. In general, wine culture is seen as having very ancient roots, which drifts to the usage of old traditions.

Concerning I+D to acquire new knowledge, investment on research is carried out only by large and medium wineries. They research on issues such as new patents on packaging systems or robots for industrialized wineries, fungi resistant varieties of grapes, or soil and microbiota studies and how tilling influences them. Income availability seems to be determinant for I+D investments, as large and medium wineries are the only ones who can afford it.

5.2. Identifying stressors: climate and beyond

In order to understand the different perceptions of stakeholders on livelihood stressors and their responses to them, questions were asked regarding changing climate parameters, as well as on other potential stressors, such as fluctuating market prices.

Both wineries and growers suggest that temperature is changing, leading to warmer summers or years, and more extreme high temperatures being recorded. Wineries also add the idea of less thermal amplitude, which includes warmer nights that badly influence grapes, and also the intuition of more insolation. Regarding the studies of Ramos and colleagues (2008), trends in Penedès indicate an average growing season warming of 0.04°C per year. Which, over the studied period (1952-2006), it represents a change of 2.2°C. Therefore, it can be proved that years are getting warmer. An increase in the number of days with extreme high temperatures is also proved, which was also stated by the interviewees, as well as a significant decline in the number of moderately extreme cold nights.

Precipitation changes are not noticed by wineries but by growers. The main argument of the vinegrowers to support such claim is that it rains less but in more concentrated periods (approximately October and March), with a longer dry period in between which is harmful for the crops. Increasing occurrence of more extreme precipitation events is also noticed. Ramos and Martínez-Casanovas (2006) studied Penedès area with an 80-years dataset (1920-2000), and they found no change on annual precipitation. However, significant change in maximum precipitation recorded in single events (1 day) or short periods (5 days) increased significantly. By seasons, this is particularly high in autumn, being also significant in summer and winter. This study partially confirms growers' views, proving that seasonality in precipitation can already be seen, but the amount of rainfall is more or less the same.

Concerning other climatic parameters, 11 out of 15 interviewees agree that maturation and harvest have advanced two weeks or more, stating that harvest used to be done in the beginning of September, and nowadays is held in the middle of August. This phenomenon influences the crops cycle and the planning of the farmers, but also affects the cultural life of the region. Historically, festivals and fairs were organised in many villages at the beginning of September. They were celebrating the starting of the harvest, and also buying machinery and other tools needed in the fairs. Nowadays, these festivities continue to exist as a tradition, but they do not correlate in time with the harvest time, loosing the historical, traditional and land-related meaning. Ramos *et al.* (2008) compared harvest dates from 1996 to 2007, proving an advancement of 3 to 7 days per 1°C warming during the growing season, confirming the interviewees' perception.

Other climatic and socio-economic stressors are mentioned by interviewees. All cavists argue that they may be affected by climate change in the quality of the wine they buy. If the varieties or organoleptic characteristics of grapes vary, basic wine produced afterwards can change too, and this may lead to less quality cava or different tastes. A change in quality or flavour may not fit in market's demand, which is a threat for all the products of the sector. Market suitability and its changes are also seen as main stressors by all the interviewees. This preoccupation was also described by Jones and Webb (2010) in their analysis of challenges and opportunities of viticulture under climate change. They argue how sensitive are grape varieties to changes in climate, but also how variable grapes and wine demand can be, since they are not crucial for human survival. Linked to that, the economic situation, together with market and fluctuating prices is a common preoccupation for wineries and growers, with the difference that growers state not noticing the current economic crisis that hard, since their normal situation is generally very complicated. Finally, water resources and their scarcity are, in general, seen as a threat for the industry. Ramos and colleagues (2008) suggested in their study in *El Penedès* region that water demand may increase between 6 and 14% per 1°C warming in the growing season, which confirms the problem noticed by the interviewees.

5.3. Linking vulnerability, adaptation and adaptive capacity

After drawing the stressors perception of the interviewees, adaptation practices were analysed, in order to seek differences, strengths and weaknesses. Perception on for whom will be easier to adapt, wineries or growers, is very erratic. Generally speaking, stakeholders think that both

groups have strategies to adapt to economic and climate changes. Wineries have more people and economic resources, but vinegrowers have the land knowledge.

Both wineries and growers affirmed changing practices in response to climate-related stressors. Growers have had to adjust the time of harvesting practices, which now have to be done earlier than before. In order regulate water competence with other plants, ploughing and pruning are more or less applied depending on the rainwater (especially after spring rainfalls). Moreover, different and new methods of trellising are being implemented, trying to cover grapes with leaves to avoid insolation excess, which is also being done by applying less pruning. Wineries have different responses among them. Large wineries implement different programs on reducing water pollution, waste assessment, emissions reduction, water and electricity consumption reduction; and follow ISO 14001 which is a continuous evaluation process that helps minimizing the operations that negatively affect the environment. Medium and small wineries work more at vine level, as growers do. They play with grass coverage, different intensities of ploughing and defoliating; or decide having lower performance on plants, lowering water needs and improving quality of the grapes. At a cellar level, they try to reduce water usage, or have water deposits for potential supply. Finally, cavists is the group that less adaptation practices is implementing. They have some “Good Cellar Practises” to reduce water usage and reuse sub-products, or try to reduce packaging materials.

When it comes to adapting to future climate change or mitigating its effects growers stated not undertaking any relevant practice. Only the farmer who was partially dedicated to agriculture noted that he was building small deposits to gather rainwater to adapt to future water scarcity. When asking if they would modify practises in the light of presumed changes in climate, responses were very vague and variable. Growers said they would not water the crops, since it would be very expensive. Some others agreed with the idea of building a small water-collecting system to water vine occasionally, in anticipation of the water scarcity that climate change may bring.

By contrary, most wineries state having already changed practices to adapt or mitigate future climate change. They try to reduce electricity consumption and invest in renewal or less-pollutant energy (e.g. solar panels, windmills, biodiesel, biomass, natural gas) and chemicals. They also use lightweight bottles or cork stoppers to reduce CO2 emissions, and try to reduce packaging materials, as well as building water deposits. Concerning future modification of practises in the light of climate changes, wineries also have different opinions. The majority stated that would modify some practises, and mentioned rainwater accumulation projects, planting at higher altitudes, changing varieties, lower crops density in order to need less water, or lower petrol dependence.

Changes in practices due to other pressing socio-economic changes are different between growers and wineries. Growers stated the need of buying new machinery and having to pay to pass new controls, buy new products or adapt crops to meet the new coming national or supranational regulations. Wineries consider increasing sales whenever it is possible, or reducing production if the economic crisis continues.

Figure 4 below summarises the relations between adaptive capacity and vulnerability of both wineries and growers. Light grey circles refer to *socioeconomic factors*, while green ones refer to *natural factors*. Different types of adaptation are painted in orange, since adaptation can be considered natural or socioeconomic.

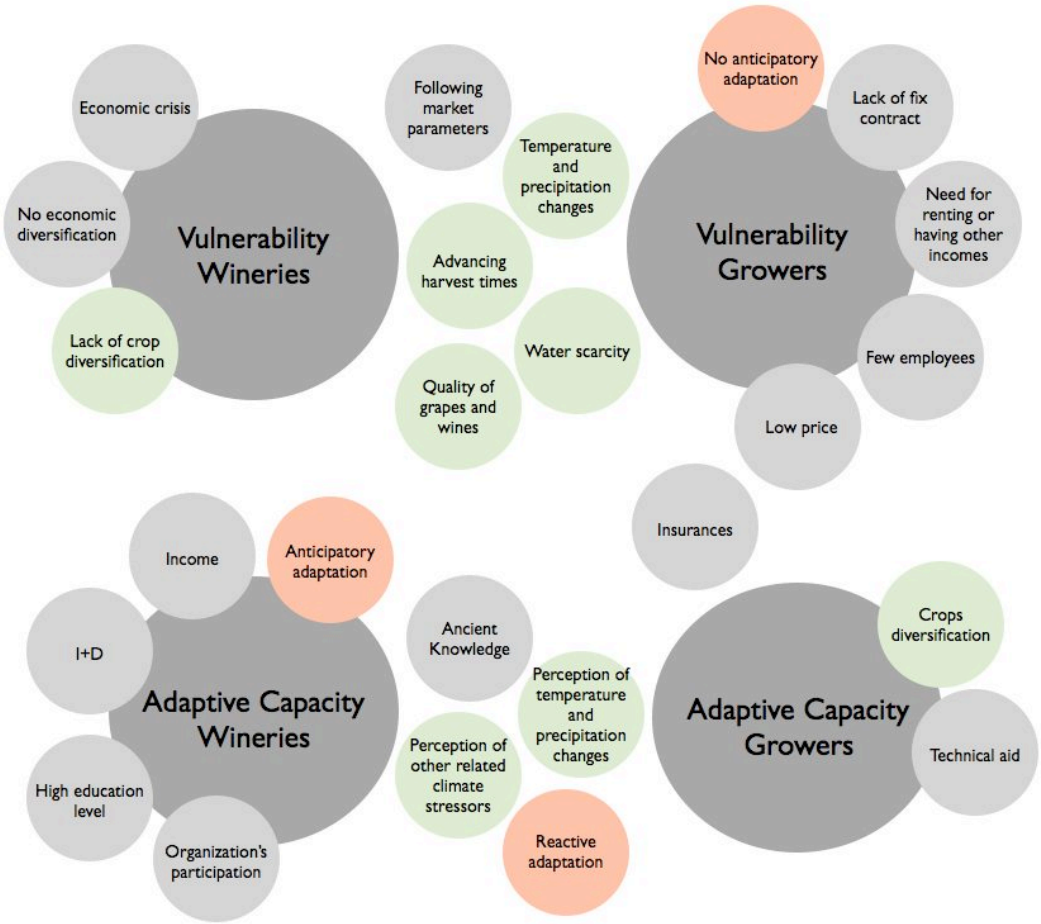
Wineries' vulnerability (top left circle) is shaped by the current economic crisis, which lowers sales and income, and the lack of economic and crop diversification, which makes wineries more vulnerable in case of market demand changes or organoleptic variations of grapes and wines. Growers conform their vulnerability (top right circle) with the lack of a fix contract to buy their grapes. They also have the necessity of renting or having other incomes to live from

agriculture, which makes difficult to make long term investments, which are in turn very necessary for vine cultivation. The fewer employees is also seen as a vulnerability because it makes them rely on friends and relatives to help in the vine work, especially if work needs to be done quickly. Low price is also an important vulnerability, and it is determined by different aspects, which are the no appreciation of local varieties, the monopoly of the companies on deciding the price, the land concentration phenomenon, which makes production cheaper, and the lack of organization of the growers. Due to many of these factors, anticipatory adaptation is in general not occurring, which in turn aggravates their degree of vulnerability. Both wineries and growers share vulnerabilities, which are located between the two circles. They both need to follow market parameters. Growers on varieties, pH, sugars and timing for grapes, while wineries need to meet changes in trends or organoleptic variations due to climate change, thus being dependent on the quality of grapes and wines. They are both affected by temperature and precipitation changes, the advancing of harvesting time and the water scarcity that will likely become more acute with climate change.

Adaptive capacity of wineries (down left circle) is shaped by the more income they have compared to growers, the higher possibility to undertake I+D research, the higher educational level and their participation in different organisations. Most of these factors allow wineries to better study and understand climate and other stressors, thus being more able to adapt to them. Anticipatory adaptation is already occurring in wineries, which reduces their vulnerability in the likely future. Adaptive capacity of growers (down right circle) is conformed by the diversification of their crops, which lowers dependence on a concrete variety, and the technical aid that they receive from specialists or plant production groups. Moreover, both wineries and growers have an ancient knowledge of their vine and cellar work that allows them coping with common stressors, as small typical Mediterranean climate variations. Furthermore, they both perceive temperature and precipitation changes, and other climate-related stressors, allowing them to have a reactive adaptation, or start an anticipatory adaptation in the likely future. Finally, insurance may be regarded as both a factor of increased vulnerability and a measure of adaptation by growers. With the sufficient income it can help them to recover from the income loss caused by frost, drought or hailing. However, insurances need an initial economic investment, which may be difficult to get by the growers, not lowering their vulnerability. Therefore, insurances can lower vulnerability depending on the initial economic situation of the growers.

Overall, it has to be stressed that *natural factors*, the ones with green circles, are normally between wineries and growers circles, meaning that are the ones shared between them. Proving that vulnerabilities but also adaptive capacities of both groups of actors are nearly the same when talking about natural assets. They are both affected by e.g. precipitation or temperature changes, the advancing of harvesting times or water scarcity. By contrary, *socioeconomic factors* are different between the two groups. Each type has its own socioeconomic threats and opportunities, like the economic crisis for wineries or the low price for growers.

Figure 4. Map of vulnerability and adaptive capacity of wineries and growers



Source: own elaboration

6. Discussion

Vulnerability of wineries and growers results from both climatic and non-climatic factors (Belliveau *et al*., 2006). In *El Penedès* region, wineries' vulnerability is shaped by the current economic crisis and the lack of diversification in economic and productive terms, which makes it more sensitive to variability and uncertainties in the agricultural sector (Eakin, 2005). Growers' vulnerability is determined by the lack of a fix contract, the need for renting or having other incomes, the few employees they have, the low price paid for their produce and the lack of anticipatory adaptation. These results partly coincide with the stressors found by Hadarits *et al.* (2010) in their study of viticulture's adaptation in the Maule region of Chile. Sensitivity of producers was shaped by market fluctuations and labour availability, which corresponds with the few employees that *El Penedès* growers have, and their necessity to rely on family and friends' help. The low price paid for the growers' produce in *El Penedès* has do with the devaluation of domestic grapes and wines, in turn due to trade liberalisation and increasing competitiveness.

Both wineries and growers are vulnerable to market parameters, temperature and precipitation changes, advanced harvesting times, water scarcity and changes in quality of grapes and wines. Battaglini *et al*. (2009) point out to the threat of the quality shift on wines and grapes in their study on winegrower's perception of climate change in Europe, confirming the general concern on this issue. Finally, Belliveau *et al.* (2006) conclude that growers are more vulnerable to changes in quality of the grapes, not in quantity, while wineries' vulnerability depends on the stress they are exposed to and their resources and technologies. This is partly true in our case study, but it seems that growers in *El Penedès* are not only affected by the quality of the grapes, but by other socioeconomic stressors like prices and wineries' demands.

The adaptive capacity of growers and wineries is shaped by their socio-economic configuration. Wineries' adaptation practices are influenced by their higher income, educational level, I+D investment and participation in farm organisations. In turn, growers' adaptive capacity relies on receiving technical support and diversifying crops. Crop diversification has shown to be strongly associated to a household's capacity to manage environmental and market risks (Eakin, 2005), and both wineries and growers apply ancient knowledge and practices to cope with and adapt to socioeconomic and climate stressors. In our case study, all stakeholders perceived climate and non-climatic threats, but only reactive adaptation was found in all actors. The lack of anticipatory adaptation in growers may be due to the lack of income available and a somewhat insufficient planning capacity. These insights contrast with Battaglini *et al*.'s (2009), who found that the majority of winegrowers perceived changing climatic conditions and, subsequently, explored a range of adaptation options.

Different adaptive responses to climate variability are observed in *El Penedès*. As stated before, growers mainly have reactive adaptation, implementing their land knowledge, ploughing or pruning more or less, trellising in different ways or play with grass coverage. Small and medium wineries also adopt such kind of reactive practices whilst large wineries have greater investments in crop management and implement different programs on e.g. reducing emissions, pollution and water usage, or work at a cellar level. Cavists only implement "Good Cellar Practises" since they do not normally have crops. Anticipatory adaptation in wineries is based on more sustainable ways of producing electricity, reducing CO2 emissions or packaging materials. It has to be stressed that partial dedication growers also have anticipatory adaptation, probably because they have other income sources a part from agriculture that allow them to have better access to the technologies, information, and knowledge necessary to proactively adapt to the effects of socioeconomic and environmental change (see. e.g. Eakin, 2005).

Smit and Skinner (2002) characterize agricultural adaptation options to climate change in Canada and describe four main adaptation strategies, namely technological developments; government programs and insurances; farm production practices and farm financial

management; and other indirect strategies such as information and training that can stimulate the other three direct strategies. Contrasting such results, technological developments mentioned by the authors are being done by wineries in our case study, farm production practices and farm financial management are implemented by both wineries and growers in *El Penedès*, government programs and insurances are not that directly noticed in our region, but information and training, especially wineries organizations to share knowledge, is a shared adaptive response.

Many of the adaptive responses identified in our study are based on the ancient knowledge that vine workers have inherited from their families. Therefore, many responses are not different from the ones in the past. However, investments on new technologies and research are new and broadening possibilities to adapt for large wineries. As Diffenbaugh *et al*. (2011) also notice studying wine industry in United States, for relatively small climate changes growers have tremendous adaptive capacity through alterations to trellising system, pruning style, row orientation and irrigation management. These small changes to buffer climate impacts are also found in our case study, mostly applying ancient knowledge and practises in vine work. The same idea is shared by Smit and Skinner (2002) who suggest that adaptation options are mostly modifications to on-going farm practices and public policy decision-making processes, with respect to a suite of changing climatic and non-climatic conditions. This is partly true in our case study, since farm practices follow the previous knowledge of the industry to cope to small climate and socioeconomic threats. In contrast, changes in policy decision-making processes were not found in *El Penedès*. However, Lereboullet *et al*. (2013) question to what extent risk management strategies that are efficient to deal with a naturally high inter-annual variability in climate may be sufficient to adapt to more extreme conditions.

In the light of everything said so far, two policy suggestions can be put forward to make the sector less vulnerable and more adaptive to climate and other stressors. First, policy could focus attention on the relationship between growers and wineries, and attempt to regulate grape prices, e.g. establishing a fair selling floor price. This would end with the economic and social instability of growers, and allow them to invest in anticipatory adaptation, reducing in turn their vulnerability to climate change. However, I acknowledge that such an approach may in turn increase wineries' vulnerability, since some of them manifested that they were able to cope with certain market risks deciding not to buy to other growers and relying only on their own grapes. This resonates with Belliveau *et al.*'s (2006) study, which also indicates that wineries' adaptation is often built on growers' increased exposure. Second, an effort to promote *El Penedès* wines needs to be done, adding value to local varieties and finding a market niche for them, thus making wineries less dependent on market demands and fluctuations and avoiding the contempt to traditional types. Belliveau *et al.*'s (2006) again show that trade liberalization in Canada's wine production sector led to a process of replacing local varieties with other more competitive ones, which were in turn more vulnerable to climate stressors. This shows the interconnectedness of the multiple risks and the dynamic nature of vulnerability, which need to be taken into account when designing new policies for economic development and adaptation in the viticulture sector.

7. Conclusion

This study has provided insights on the vulnerability and adaptive capacity of the viticulture sector in *El Penedès* region, Catalonia, looking particularly into the differences and similarities of growers and wineries and on how to better design possible policy interventions. Vulnerability has understood to be a function of the character, magnitude and rate of climate change and the variation to which a system is exposed, its sensitivity and its adaptive capacity. Results have shown that the biophysical stressors induced by the already changing climate (e.g. water scarcity, advanced harvesting, raise in temperatures, among others) are felt equally by both types of stakeholders. Thereby, the exposure of wineries and growers to these threats is the same, but not their sensitivity. Different types of stakeholders cope climate and socioeconomic stressors in different ways, depending on their economical, technological, human and social capital.

Understanding wineries and growers' vulnerability to climate change and their adaptive responses is not only about examining whether more or less water will be available in the future, or whether harvest will need to occur earlier or later in the year. It is also about having the income, the information and the awareness necessary to adapt and understand which social and economical conditions permit or not adaptation. In our case study, growers seem more vulnerable or have less adaptive capacity than wineries due their variable income and contract type, and the fewer employees they have. Furthermore, the unequal relationship of produce exchange between wineries and growers, their different vulnerabilities and adaptation options may bode different problems to wine regions. For example, the variable and low income of growers may lead them to diversify their income, having other jobs or, in extreme cases, abandon agriculture. This may translate into a loss of culture and local traditions, to landscape changes and to the concentration of property. In other circumstances, changes in demand may make growers switch varieties, due to the fact that some foreign ones are better sold. This would lead to a loss of local grape varieties and cultivation practices.

It seems that growers (and also some wineries) have the inherited knowledge to cope with climate fluctuations. However, it cannot yet be foreseen if these techniques will be sufficient to buffer further climate variability. Anticipatory adaptation is needed to protect the work of the industry and the ancient culture surrounding it. In order to foster it, policy interventions need to be designed, minimizing the economic impacts of growers and protecting the singularity of regional wines, facilitating the implementation of long term strategies to adapt to a changing climate.

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