Assessing the climate change vulnerability of European winegrowing regions by combining exposure, sensitivity and adaptive capacity indicators

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Abstract

Winegrowing regions recognized as protected designations of origin (PDOs) are increasingly threatened by climate change, which is affecting local conditions and winegrowing processes. However, the vulnerability to climate change is determined by individual characteristics of each region, including natural, socioeconomic, and legal factors, and is therefore largely heterogeneous between regions. Vulnerability assessments thus need to consider multiple variables and their interrelations to provide an accurate understanding of the expected impacts of climate change on European PDOs. Here, we present the first vulnerability assessment for selected European wine PDOs that spatially combines multiple indicators of adaptive capacity and climate change sensitivity with high-resolution climate projections. We found that the climate change vulnerability of PDO areas largely depends on the complex interactions between natural, physical and socioeconomic factors. Regions with high exposure thus might still have a low vulnerability, depending on their sensitivity and adaptive capacity. Our approach combines multiple factors related to climate exposure, sensitivity, and adaptive capacity on the level of single winegrowing regions and can easily be extended to other regions. The results will help to identify hot spots of climate change vulnerability among European PDOs and efficiently direct adaptation strategies.

Introduction

Winegrowing regions provide not only economic benefits, but also multiple environmental, cultural and social values (Winkler et al., 2017). Most winemaking regions, especially those producing wines under the Protected Designation of Origin (PDO) label, are highly susceptible to the impacts of climate change because their products are tied to specific environmental conditions and cultivation techniques. In fact, many regions already observed altered wine characteristics caused by changes in climatic conditions (Leeuwen et al., 2019). To maintain their traditional wine products, winegrowing regions therefore must develop specific adaptation strategies, which includes the adoption of new cultivation techniques, changes in plant material or relocation of vineyards (Leeuwen et al., 2019).
To identify the most vulnerable regions and develop efficient adaptation strategies, climatic as well as legal, natural and socioeconomic characteristics have to be considered. For instance, regions that cultivate a higher genetic diversity of grape cultivars have been shown to be less vulnerable to climate change (Morales-Castilla et al., 2020). Additionally, social characteristics, such as age structure or rural depopulation, natural characteristics, such as the presence of climatic niches, or the financial situation of winegrowing regions strongly determines their possibilities for climate change adaptation (Greiving et al., 2011; Vigl et al., 2018). Although multiple studies already examined the direct impacts of climate change on phenology and wine

quality, a comprehensive analysis focusing on the vulnerability to climate change for single winegrowing regions is still missing.
To address this research gap, we analyzed the climate change vulnerability of selected European PDO regions by combining future projections of climate change with legal and socioeconomic indicators related to their adaptive capacity. Our aims were to (1) assess the climate change vulnerability of selected European PDO regions and (2) compare regions with similar climatic and topographic characteristics against each other to identify critical drivers of climate change vulnerability.

Materials and methods

Winegrowing regions and climate data

For the present analysis, we used 12 European PDO regions which span different climatic and topographic conditions from Candiago et al., (in review)). We selected relevant regions based on the Koeppen-Geiger climate classification (Beck et al., 2018) and the landform classification from Meybeck et al., (2001) (Table 1). For the climatic analysis, we used the CHELSA database that includes pan-european, downscaled temperature and precipitation data at 1km horizontal resolution (Karger et al., 2021). The timeframes 1981-2010 and 2070–2101 were used as present and future reference period, respectively. The climate projections were calculated based on a 5 model ensemble (GDFL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0, UKESM1-0-LL) from the ssp585 scenario.

Table 1. The PDO regions considered in the present study, classified into 4 groups based on the Koeppen-Geiger classification as well as topographic criteria. MVA = mountain viticultural areas

Group	PDO Name	Country	Koeppen Class	Landform
Arid	La Mancha	ES	Arid	Plains
Arid	Γουμένισσα	GR	Arid	Lowlands
Arid	Tavoliere	IT	Arid	Plains
Cool-Climate	Würzburger Stein-Berg	DE	Cold	Plateaus
Cool-Climate	Sachsen	DE	Cold	Plains
Cool-Climate	Dons	DK	Cold	Plains
MVA	Alsace grand cru Osterberg	FR	Cold	Mountains
MVA	Südtiroler	IT	Cold	Mountains
MVA	Valle d'Aosta	IT	Cold	Mountains
Temperate	Bourgogne	FR	Temperate	Plateaus
Temperate	Reggiano	IT	Temperate	Plains
Temperate	Douro	PT	Temperate	Hills

Climate change vulnerability

In the present framework, climate change vulnerability consists of three components: exposure, sensitivity and adaptive capacity (Haines, 2003) and each component consists of several indicators (Table 2). Exposure describes the expected climate trend in a region between the periods 1981-2010 and 2071-2100, while the sensitivity describes how a region is impacted by climate change. For instance, winegrowing regions with very warm or dry climatic conditions have a high sensitivity, because a small increase in air temperature or a small decrease in precipitation might push these areas outside the suitable range of climatic conditions for viticulture. To calculate the adaptive capacity of the PDO regions, we collected and homogenized statistical indicators from six dimensions of sustainable development (Ellis, 2000), including financial, legal, natural, social and human characteristics (Table 2). To be able to combine the indicators, all of them were first scaled to values between 0 and 1 using linear min-max normalization and then averaged per component. Finally, the vulnerability was calculated using the formula: V= E*S*(1-AC), with E as exposure, S as sensitivity, AC as adaptive capacity and V as vulnerability.

Table 2. Indicators used for calculation of the three components. OSM = Open Street Map, CHELSA = Climate data from the CHELSA database, CLC = Corine Land-Cover 2018, FADN = Farm accountancy data network, Census Hub = Census data from Eurostat

Component	Dimension	Indicator	Source
Exposure		Change in annual temperature	CHELSA
		Change in annual precipitation	CHELSA
Sensitivity		Huglin index	CHELSA
		Cool night index	CHELSA
		Dryness index	CHELSA
Adaptive capacity	Social	Aging index	Census Hub
		Total dependency ratio	Census Hub
		Population density	Census Hub
	Physical	Road length	OSM
	Natural	Capacity to shift in space	CLC; CHELSA
		Climate Moisture Index	CHELSA
		Topoclimatic variability	CHELSA
	Legal	Number of allowed varieties	Candiago et al., (in review)
	Human	Regular labour force input	Eurostat
		Training of farm managers	Eurostat
		Proximity to research centres	Eurostat
	Financial	Farm solvency	FADN
		Return on assets	FADN
		Subsidies dependency	FADN

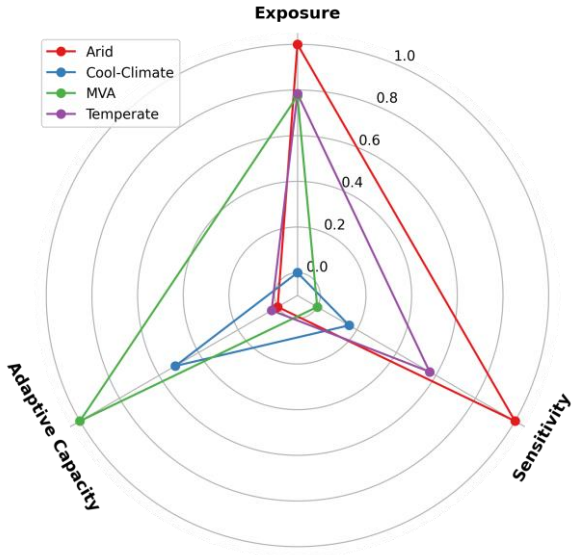

Figure 1. Scores for exposure, sensitivity and adaptive capacity for the four groups of winegrowing areas.

Results and discussion

The selected PDO regions show clear differences in their exposure, sensitivity and adaptive capacity depending on their climatic and topographic characteristics. For instance, PDO regions in the arid group have the highest exposure and sensitivity combined with the lowest adaptive capacity and therefore are the most vulnerable to climate change. This is in-line with many previous studies that highlight the increased vulnerability of winegrowing regions in the Mediterranean regions (Fraga et al., 2016). Similarly, PDO regions in the temperate group have a high exposure and sensitivity coupled with a low adaptive capacity and are therefore also characterized by a high vulnerability. The PDO regions in the cool-climate group have a very low exposure

and sensitivity, as well as a high adaptive capacity and in turn are less vulnerable to climate change. These winegrowing regions could even experience positive benefits from climate change (Jones & Schultz, 2016). Mountain viticultural areas (MVA) have a very high exposure, because climate change tends to proceed faster at higher elevations and in mountain terrain (Pepin et al., 2015). However, the selected mountain regions also have a low sensitivity, and a very high adaptive capacity, mostly related to the topoclimatic variability and capacity to shift in space in complex topography (Vigl et al., 2018). Consequently, their vulnerability to climate change is much lower compared to arid and temperate regions, despite similar exposure.

There are also strong differences between the groups of PDO areas regarding the different dimensions of adaptive capacity (Figure 2). MVA have the highest potential for adaptation, due to their complex topography, which improves the availability of climatic niches as well as the possibility to shift vineyards to areas with cooler climatic conditions (Vigl et al., 2018). Adaptation in MVA is mostly limited by the low availability of physical infrastructures, such as roads, which could hamper structural changes in vineyards that are critical for climate change adaptation (Greiving et al., 2011). Arid and temperate PDOs have a very low overall adaptive capacity, especially in the natural and social dimensions. However, they have a lot of economic potential, which could be used to finance adaptation strategies and improve the capacity in the other dimensions. The high adaptive capacity of cool-climate winegrowing regions is caused by the social, natural, physical and human capacities. However, they have very low scores for the legal capacity, related to the lower number of varieties that are cultivated in these regions, and the financial capacity.

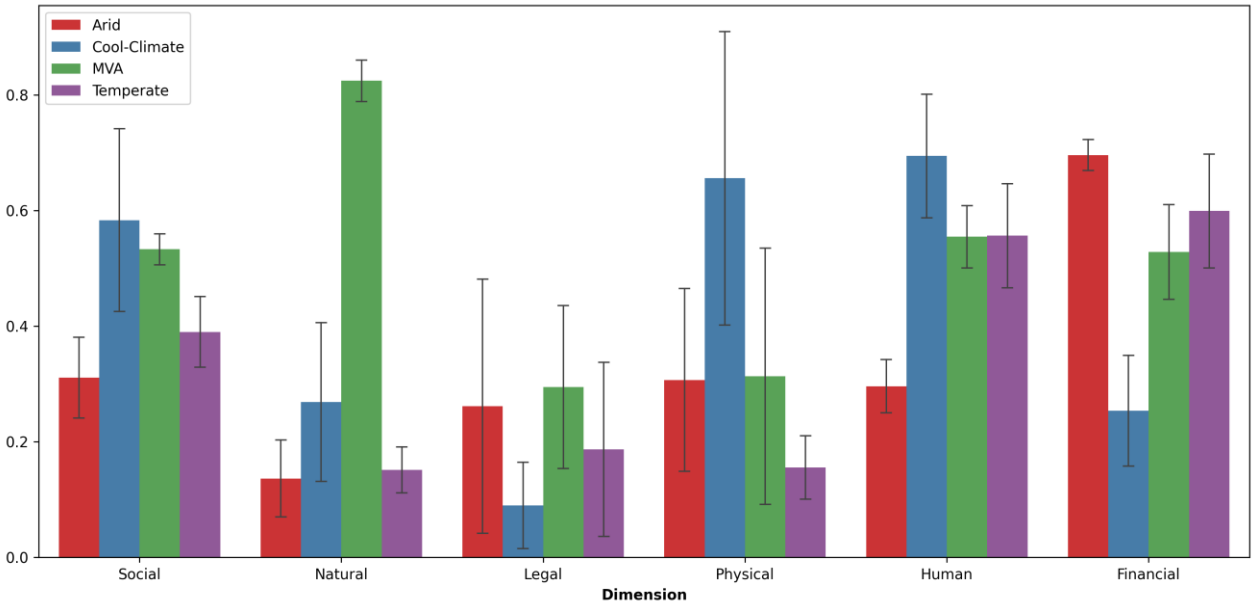

Figure 2. Scores for the six dimensions of adaptive capacity for each PDO group.

Conclusion

High-quality winegrowing areas are particularly threatened by climate change, with negative impacts on their economic, social, and cultural benefits. However, the vulnerability to these changes is highly heterogeneous between regions and an accurate vulnerability assessment needs to consider the socioeconomic, natural and legal characteristics of individual regions. By highlighting the most important strengths and weaknesses of our selected regions, we provide critical information to develop tailored and effective adaptation strategies. The results of this study will be further expanded by including additional PDO regions throughout Europe to provide more general conclusions, identify hotspots of climate change vulnerability and help to maintain the traditional wine style of European PDOs under future climate conditions.

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