Available online at www.sciencedirect.com

ScienceDirect

Wine Economics and Policy 7 (2018) 165–177

www.elsevier.com/locate/wep

Adaptive capacity to climate change in the wine industry: A Bayesian Network approach

Eva Merloni[a], Luca Camanzi[b,*], Luca Mulazzani[b], Giulio Malorgio[b]

[a]*Inter-Departmental Research Centre for Environmental Science, University of Bologna, via S. Alberto, 163, 48123 Ravenna, Italy*
[b]*Department of Agricultural and Food Sciences, University of Bologna, viale G. Fanin, 50, 40127 Bologna, Italy*

Received 1 June 2018; received in revised form 26 October 2018; accepted 9 November 2018
Available online 12 December 2018

Abstract

This study assesses the main factors influencing the behavior of wine producers and the strategies implemented by them with regard to changing climatic conditions. To do so, we adopted a Bayesian Network combining climatic, technical, and economic factors, as well as farmer perception and environmental actions. Based on the scientific literature reviewed, a set of research hypotheses was formulated and compared with empirical evidence collected in the Italian region of Emilia-Romagna. Climatic data, both at the regional and vineyard levels were collected and primary information on wine growing and wine making firms was gathered by means of a producer survey, including 56 wine farms. The results showed that the probability to be negatively affected by the effects of climate change is influenced by structural and technical farm characteristics and by farmer readiness to embrace change. Local climatic conditions, particularly temperature and water surplus, are the factors that most affect both wine production and adaptation behavior in the study area. We conclude that the adoption of focused management and appropriate adaptation strategies, as well as appropriate policies with regard to regulation, incentives and support, are crucial issues for farmers to face the ongoing climatic challenge.
© 2018 UniCeSV, University of Florence. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Keywords: Climate change; Adaptive capacity; Wine sector; Bayesian Network

1. Introduction

The strong impact of climate change on wine production is widely recognized (Stock et al., 2005). In fact, wine grape yield and quality are largely dependent on climatic conditions, particularly during the growing season (Urhausen et al., 2011; van Leeuwen et al., 2004), while weather fluctuations are likely to occur over the thirty years of a vineyard life cycle. Among the many climatic factors affecting wine production, temperature appears to be most important (Ruml et al., 2012). Sustained higher temperatures can have a negative impact on grape and wine quality, while relatively constant intermediate temperatures and minimal day to day variability during the months of growth and ripening, are beneficial (Gladstones, 1992). Precipitation and its seasonal distribution are also very important, as water is crucial for the vine at the beginning of the growing season, from budburst to inflorescence development, while dry, stable conditions are needed from flowering to ripening (Ramos et al., 2008).

The main effects of climate change on wine production entail increasing incidence of plant diseases, variations in sugar and alcohol content (thereby, in chemical and organoleptic characteristics of wine), leaching out and soil erosion (Ashenfelter and Storchmann, 2014; Anderson et al., 2008),

*Corresponding author.
E-mail addresses: eva.merloni@unibo.it (E. Merloni), luca.camanzi@unibo.it (L. Camanzi), luca.mulazzani@unibo.it (L. Mulazzani), giulio.malorgio@unibo.it (G. Malorgio).
Peer review under responsibility of UniCeSV, University of Florence.

https://doi.org/10.1016/j.wep.2018.11.002
2212-9774/© 2018 UniCeSV, University of Florence. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

which in turn have strong repercussions on firm competitiveness and profits (Anderson, 2017).

Indeed, an increasing number of studies are focused on the most appropriate adaptation practices and strategies to maintain the vitality of the wine industry (Mozell and Thach, 2014, Nicholas and Durham, 2012), as well as the potential adoption of adaptation and mitigation behaviors (Camanzi et al., 2017; Niles and Mueller, 2016, Sacchelli et al., 2016).

The factors affecting farm adaptive capacity are both intrinsic (such as producer age and educational level) and extrinsic (such as the institutional, political and climatic conditions) (Reidsma et al., 2009; Vincent, 2007). Nevertheless, adaptive capacity is also affected by the willingness of farmers to change their behavior (Niles and Mueller, 2016) and by producer perception with respect to environmental sustainability and the impacts of climate change. The most highly accredited definitions of adaptive capacity do consider the subject of behavioral change (Reidsma et al., 2010; Smit and Wandel, 2006). However, the issues of producer perception on environmental sustainability and the impacts of climate change have not been given sufficient attention in the scientific literature (Niles and Mueller, 2016; Lereboullet et al., 2013).

Notably, adaptation is often conceptualized as a site-specific phenomenon. In fact, many authors call for more local-level analyses to have a better understanding of the fundamental processes underlying adaptation and for better targeting adaptation policies by national and local governments (Below et al., 2012; Smit and Wandel, 2006). However, as Vincent (2007) has rightly claimed, there is a need for a method to assess the adaptive capacity, which is specific enough to capture local variation and yet, transferable to other sites.

This research investigated the main drivers for the adaptive capacity in the wine industry at a local level that will support wine makers in their efforts to maintain and improve their productivity in a long-term perspective. Specifically, the study provides:

- an evaluation of the short and long-term adaptation measures during sensitive years;
- a measurement of the agronomic and economic impact of climate change during sensitive years;
- an assessment of the relationship between adaptation drivers, agricultural practices, farm strategies and their impacts in the wine sector.

The remainder of the paper is structured as follows. In section two we lay down the conceptual framework of the study and we formulate a set of research hypotheses concerning the relations between (i) adaptation drivers, (ii) adaptation practices and strategies and (iii) economic and agronomic impacts. Section three describes the methods and data used in the study. More precisely, a Bayesian Network approach, which allows to weigh climate change impacts in probabilistic terms and to assess the relation between the different variables, is adopted and calibrated through a farm survey conducted on a convenience sample of 56 wine growing and wine making farms on a particular case study - the Sangiovese wine in the Emilia-Romagna region (Italy). Finally, the results of the study are presented and discussed in Section 4.

2. Conceptual framework

Drawing from the definitions proposed by Belliveau et al. (2006) and Fraga et al. (2012), in this study we refer to adaptive capacity as the ability of a system to recover or adapt to changing local external conditions, reducing their negative impacts through the possibility to implement adaptation practices in a short-term perspective (reactive adaptation practices), and anticipating future impacts and changes with long-term strategies (adaptation strategies).

The conceptual framework proposed draws upon two main theoretical approaches: Behavioral Economics (Artikov et al., 2006; Hu et al., 2006) and the Natural Resource-Based View of the firm (NRBV) (Hart, 1995). Behavioral Economics can explain the intentions for adopting specific adaptation practices and strategies in the context of climate change. In fact, research using environmental behavior theories has demonstrated the association between beliefs, knowledge of an environmental issue, and behavioral change (Ajzen, 1991). With regard to climate change, perception of personal experience affects belief in climate change and adoption (intended or actual) of climate adaptation and mitigation behaviors (Spence et al., 2012; Broomell et al., 2015). The NRBV theoretical approach traces the link between environmental actions and profit and focuses on the capacity of farms to gain competitive advantages, while coping with the challenge of irreversible environmental change (Michalisin and Stinchfield, 2010). Some authors (Cuerva et al., 2014; Hadjimanolis, 2000) highlighted the role of firm characteristics and resource availability (natural resources and human capabilities) as determinants of technological innovativeness in small firms. The former include entrepreneurial culture, informal processes and flexibility; the latter relate to technological information, machinery adaptation and design capability. Further, farms that choose more sustainable business philosophies are more likely to be successful due to resource preservation, production optimization and environmental protection (Graedel and Allenby, 2002). "Environmental" actions are considered one of the most rational business behaviors in terms of increased efficiency, protection of nature, future security and sustainability. Moreover, they are also essential to communicate with environmental organization and to educate consumers (Banerjee, 2002; Fraj-Andrés et al., 2009), winning their confidence and support to increase sales of goods or services (Genç, 2013). The association between environmental initiatives and organizational performance has been analyzed in several studies (Orlitzky et al., 2003) and a positive relationship has been demonstrated (Genç, 2013). Examples of environmental actions related to climate change include the reduction of greenhouse gas emission and the use of energy from renewable resources (Hart, 1995).

For small enterprises, Aragón-Correa et al. (2008) indicate that the adoption of proactive environmental practices leading to superior financial performance (i.e. reduced costs) “is associated with specific organizational capabilities based on their unique strategic characteristics of shorter lines of communication and closer interaction, the presence of a founder's vision, flexibility in managing external relationships, and an entrepreneurial orientation”. Size is a relevant but not a deterministic condition for developing the most proactive environmental strategies.

Drawing from previous studies, López-Gamero et al. (2009) argue that “there is a positive relationship between early investment timing and intensity of involvement in environmental issues and the adoption of proactive environmental practices that involve better firm performance (…) in terms of costs and differentiation”. The two groups of items used to measure the extent to which firms were proactive in environmental management include both organizational aspects and technical aspects of environmental management.

Finally, Hart and Dowell (2011) highlight the need for “a focus on innovation and future positioning as the metric for success” as well as the importance to develop “abilities to deal with areas of knowledge that are uncertain, constantly evolving, and dynamically complex”.

In light of the literature reviewed, the first research hypothesis formulated concerns the linkage between farm characteristics, producer perceptions of climate change and adaptive capacity (Fig. 1). Previous studies showed that the capacity of wine-growing farms to implement effective adaptation actions depends on their socio-economic characteristics (Bernetti et al., 2012), such as type of business, size, financial availability, and available technology (Olesen et al., 2011). In addition, farmers' adaptation is linearly dependent on their perception of external climate variables (Belliveau et al., 2006). Hence, we stated the following research hypothesis:

H1. *Do farm characteristics and producer perceptions of climate change affect farm adaptive capacity acting on the possibility to implement reactive adaptation practices*?

The second research hypothesis considered links reactive adaptation practices, environmental actions and magnitude of climate change impacts. According to Antle et al. (2004), vulnerability of an agricultural system depends on the degree of adaptation, with a negative relation in "non-adaptation" scenarios and a positive relation in "adaptation" scenarios. A recent review by Nicholas and Durham (2012) concluded that the ability of agriculture to adapt to climate change can increase considerably, within acceptable heating ranges, applying the right agricultural practices and using existing technologies. Based on these considerations and following Below et al. (2012), we expect that farmers applying a large number of effective practices can better respond to climate change, thereby reducing its impacts at both agronomic and economic levels.

Moreover, some authors have indicated that farms with more sustainable business philosophies are more successful than those simply oriented to the environment in a more passive manner (Graedel and Allenby, 2002). In fact, a positive relationship between environmental and financial performance has been demonstrated, especially for large-scale farms, in various studies (Genç, 2013; Orlitzky et al., 2003). For the purposes of this study, we choose to assess the

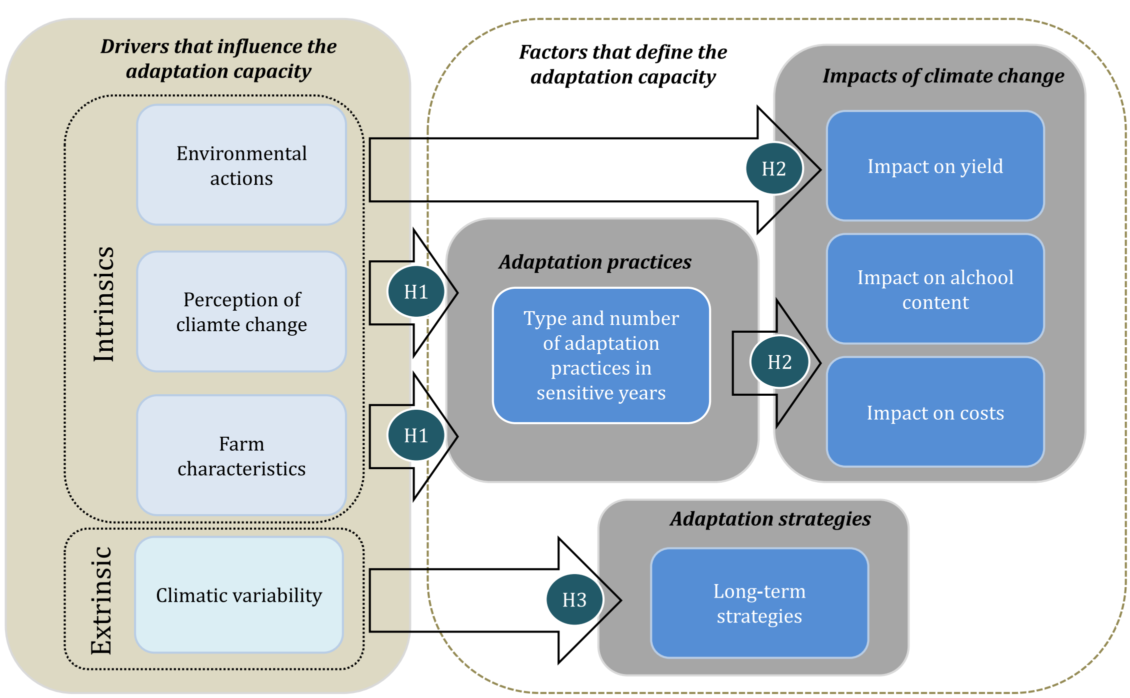

Fig. 1. The conceptual framework of the study.

environmental actions detecting the environmental and process certifications (Organic farms and ISO certification) and the sustainability practices (renewable energy, water reuse, recycling, etc.) implemented by producers. Hence, we state the following research hypothesis:

H2. Do the type and/or number of adaptation practices and environmental actions reduce the negative impacts of climate change?

The third research hypothesis investigated considers the between farm characteristics, producer perceptions and local climatic variability, with adaptive capacity of the farm in a long-term perspective, considering the producer's intention to implement adaptation strategies.

Besides the structural characteristics of farms and producer perceptions, in a context of climate change it is necessary to take into account the local characteristics of the system (Smit and Wandel, 2006). In particular, local climatic conditions can strongly influence both, the choice of adaptation practices and long-term strategies to implement as well as the risks and impacts that farms face. The vulnerability of the system is represented by local characteristics and external climate variables (O'Brien et al., 2004; Smit and Wandel, 2006). Precipitation and temperature are factors that can influence the adoption of specific agricultural practices (Gbetibouo, 2009; Deressa et al., 2009) and the change in the short-term pattern directly influences the day-by-day adaptation, while we expect long-term climatic variability to strongly influence the choice to implement permanent strategies. Hence, we state the following research hypothesis:

H3. Do farm characteristics, producer perception of climate change and climatic variability experienced at the farm level affect the intention to implement adaptation strategies?

In conclusion, the conceptual framework proposed examines the relationship among intrinsic factors (environmental actions, perception of climate change and farm characteristics) and extrinsic factors (climatic variability) affecting farm adaptive capacity in terms of both short-term impacts of climate change and adaptation practices, and long-term adaptation strategies (Fig. 1).

3. Data and methods

3.1. Bayesian network

A Bayesian network (BN) is a semi quantitative approach that facilitates learning about causal relationships between variables, integrating social, ecological and economic factors (Bromley et al., 2005) to assess the process of adaptive management (Smith et al., 2007; Richards et al., 2013). BN represent a system through a series of variables joined by causal links. They provide a qualitative conceptual representation of cause and effect, and then quantify the strengths of those relationships through conditional probability tables (CPTs) (Ticehurst et al., 2011).

The Bayesian Network approach was chosen in order to provide an overall assessment of the cause-effect relationships between a large number of variables at once. Thus, the BN model was built starting from the conceptual framework depicted in Fig. 1 and the assumptions underlying the structure of the BN are listed in Table A1 in the Appendix. Then, The BN was populated by empirical data using the Netica software. In particular, farm characteristics, climate change perception, environmental actions (these three variables resulted from cluster analysis) and the two indices of climate variability were used as initial inputs of the model. These nodes may affect differentially the implementation of short-term (reactive) practices, and long-term (structural) strategies. Short-term practices were considered separately in the case of dry, rainy, and hot years. Finally, we assessed the effect that the combination of environmental actions and practices on the agronomic and economic outputs of the farm, in particular on yield, alcohol content and costs.

3.2. Data collection

Since adaptive capacity is a complex, multidimensional phenomenon usually composed of several components that aggregate indicating variables, Hinkel (2011) suggested that it should be analyzed for well-defined systems, where variables are available to develop deductive reasoning. Following this approach, we decided to focus the empirical assessment of farm adaptive capacity in a specific case study area, subject to climate variability, the Emilia-Romagna region (Antolini et al., 2016; Busuioc et al., 2008).

The Emilia-Romagna region is an important, traditional wine producing territory in Italy, home of about 5,090 wineries and 23,000 wine-growing farms with an average vineyard area of 2.2 ha, for a total of 55,929 ha (ISTAT, 2010). It is among the first three Italian regions for the production of wine with 8.7 million hectoliters produced (about 17% of the whole Italian production) in 2016, The prevalent wine production in the region is represented by 'Sangiovese', a highly sensitive grape to climate change effect. The area mainly specialized in the production of 'Sangiovese' is the Romagna area, in the southeast (Fig. 2). Sangiovese is one of the more iconic vine varieties in Italy, being cultivated in several regions. "Sangiovese di Romagna" has been certified with the DOC label since 1967. In Romagna, wine farms are geographically close and the interaction leads to an increase in the level of innovation by individual farms through the exchange of knowledge (Pouder and St. John 1996). Climate change has been largely studied in the region, especially for its impacts on the agriculture sector. In particular, the change is represented by hotter temperatures, decreasing precipitations (especially in mountain and hilly areas) and increase in extreme events. In particular, since 2001 the southern area of the Region (Rimini province) experienced a high thermal variability, directly correlated with the presence of water stress phenomena. On the other hand, the hilly and pre-hill areas not adjacent to the coast (provinces of Forlì-Cesena, Faenza, Imola and Bologna) recorded high water surplus values in the period of ripening of the grapes, entailing

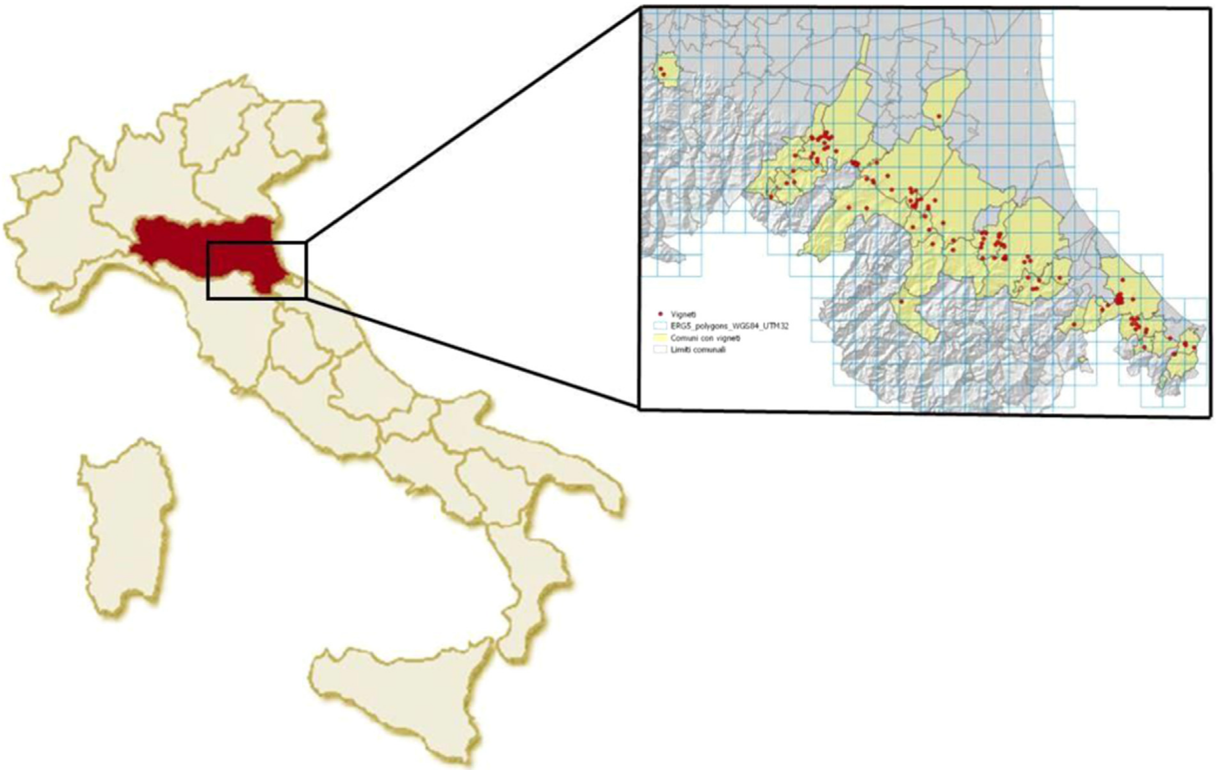

Fig. 2. The study area and sample.

a considerable reduction in the quality and volumes of wine obtained (especially in 2017).

The study targeted heterogeneous information, including climatic, technical and economic data which we collected from both secondary and primary sources.

Climatic data include data at regional and at the vineyard levels. Monthly data concerning minimum and maximum temperature and precipitation for the period 2001–2016 were gathered from the climate records of the Emilia-Romagna Regional Authority and the database of the Regional Agency for the Protection of the Environment and Energy (ARPAE). Then, the average values of temperature and precipitation have been calculated at regional level to define the three years most affected by different effects of climate change in the last 15 years; thus, the rainiest, hottest, and driest years of the period have been identified. Among these, 2003 was the hottest year, 2012 was the driest year and 2014 was the rainiest year.

Minimum, average and maximum temperature and precipitation have been collected at the nearest weather stations to the vineyards of each farm. Geographical coordinates of the vineyards were provided by the Emilia-Romagna regional agency for intervention in agriculture 'Agenzia per le Erogazioni in Agricoltura' (AGREA). These coordinates allowed the classification of the wine farms involved in the research, on the basis of temperature and precipitation variability.

Technical and economic data were collected by means of a mixed-mode survey (administered by email, by telephone and face-to-face) conducted on a selection of wine farms in the study area described above. For the purposes of the study, the survey was targeted only to professional farms (i.e. those with at least two hectares of vineyard) producing Sangiovese in their own cellar. With the collaboration of local Consortia and Certification bodies, 190 farms were identified as the reference statistical population of the survey and requested to participate in the survey. Among these, 59 agreed to participate and 56 questionnaires were appropriately completed (29.5% response rate). Hence, the sample provides significant evidence of the phenomena investigated within the region.

The questionnaire was divided into four main sections:

(1) The perception of the wine growers with respect to environmental sustainability and the impacts of climate change.
(2) The reactive adaptation practices and long-term adaptation strategies. Adaptation practices include cultivation practices (phytosanitary treatment, leaf removal); soil management (irrigation, soil preparation etc.); harvesting practices (mechanical, manual); harvesting date (upfront, postponed), and winemaking process (selected yeasts, blend). Adaptation strategies considered are mainly related to the producer's intention to move, in the near future, to new rootstocks, new varieties, or to change farming practices.
(3) The effects of climate change on vine and wine production investigated on the basis of the historical records of the

farmers for the rainiest, the hottest and the driest seasons in the 2001–2016 time period.

(4) The general characteristics of the vine growing and wine making producers and farms.

Both open-ended questions and closed-ended questions were included in the questionnaire. Most of them where assessed with a five-point Likert scale to gather attitudinal or preferential data from respondents.

3.3. Data analysis

In order to assess interviewees' awareness of changing climatic conditions and to check their accuracy in reporting the information targeted in the questionnaire, they were required to indicate three vintages corresponding to extreme climatic conditions in the 2001–2016 time period. Most interviewees correctly indicated the three years that had been already identified as the most sensitive ones, based on the data provided by the Emilia-Romagna Regional Authority and ARPAE.

The reliability of their answers concerning the practices adopted and the economic performances obtained in each year is reinforced by two further elements. First, all the interviewees report that they keep written records of their activity. Secondly, none of them choose the "don't know/ don't remember" option that was available for each item in the questionnaire.

As a second step, the surveyed farms were classified based on the climatic variability observed in wine growing areas of each farm. Climatic variability was assessed by means of the standard deviation of the variables listed below reported for the vineyards of each farm:

- Winkler index (Jones and Schultz, 2016), calculated for the vegetative period of the vine (April-October);
- water surplus values, calculated for each farm during the most critical time period for the grapes: the ripening (September–October).

The 56 wine farms were classified on the basis of the median of the standard deviation values for these climatic variables. Wine farms with values above the median were classified as "high variability", while those with values below the median were classed "low variability".

As a third step in the analysis, we searched for homogeneous groups of farms based on drivers that may affect farm adaptive capacity. Three cluster analyses, conducted through SPSS software, subdivided the sample in relation to the specific groups of variables, based on the drivers that influence the farm adaptive capacity analyzed before: characteristics of wine and wine making farms, climate change perception and environmental actions (the list of drivers is displayed in Table 3). A two-step clustering process was used for variables representing farm characteristics and environmental actions groups (since they are both categorical, and non-categorical), while the agglomeration hierarchy algorithm with the full link, square Euclidean distance method was used in the case of the climate change perception group (binary data).

Finally, both the classification of farms based on climatic variability (i.e. Winkler index and water surplus) and the results of the three clustering procedures performed were be used as the basis to present the results of the BN (see Fig. 1).

Further insights on the statistical significance of the relationships between specific variables were provided by means of Chi-squared tests.

4. Results and discussion

4.1. Overall sample characteristics

The information collected show that on average farms surveyed are small-sized (18 ha) with a limited use of mechanized harvest (42%) while the large majority of them (80%) follow sustainability practices, such as sustainable water management, renewable energy system, etc.

Overall, producers reported to be aware of the ongoing change in climatic conditions and identify temperature and rainfall as the environmental factors that mainly affect wine production, in accordance with the assumptions of the study.

As far as adaptation practices are concerned, the results of the survey point out that the largest variations in adaptation practices occur in the rainy year, followed by hot and dry years (Table 1).

The most frequent adaptation practices entailed by extremely rainy conditions during the year include changes in cultivation practices (86%) – namely more frequent phytosanitary treatments (75%), and soil management practices (34%), making cuts in the middle of the rows to facilitate water drainage. Major variations are also reported in the harvesting dates (that are postponed in the 48% of cases) and the adoption of manual harvesting in place of mechanical harvesting (17%). Farmers are also induced to adapt their winemaking process (43%), in particular by selecting appropriate yeast and blending. Further practices include enrichment, short maceration, and adding sulphites. Eventually, even the marketing strategy of farms needs some adjustments in rainy years, as, due to excessive rainfall, reserve wines cannot be produced and farmers end up selling most of the wine to other cellars or to Large-Scale Retailers.

Hot and dry years register similar variations in adaptation practices. As a first reaction, harvesting dates are anticipated by the large majority of farmers (64% in the hot year and 50% in the dry year). Then, significant changes in cultivation practices are reported (52% and 32% in hot and dry years), most often intensifying phytosanitary treatments. Soil management in the hot and dry years also need some adaptations, particularly concerning soil preparation practices entailing higher rates of mechanical work and plowing to increase soil humidity. Finally, some modifications concern the winemaking process (about 20% of

Table 1
Adaptation practice variation in the targeted years.

	Hot year (2003)	Dry year (2012)	Rainy year (2014)
Cultivation practices	**52%**	**32%**	**86%**
of which:			
Phytosanitary treatments	33%	23%	75%
Leaf removal	0%	4%	6%
Nocturnal foliage	2%	2%	0%
Soil management	**34%**	**25%**	**34%**
of which:			
Irrigation	6%	2%	0%
Soil preparation	15%	12%	9%
Grassing	2%	2%	20%
Rupture grassing	7%	7%	0%
Harvesting practices	**11%**	**16%**	**25%**
of which:			
Mechanical	0%	3%	8%
Manual	11%	13%	17%
Harvesting date	**64%**	**59%**	**68%**
of which:			
Upfront	64%	50%	20%
Postponed	0%	9%	48%
Pruning mode	**7%**	**5%**	**14%**
Winemaking process	**21%**	**20%**	**43%**
of which:			
Yeast selection	11%	11%	13%
Blends	5%	6%	13%
Marketing strategies	**4%**	**4%**	**29%**

interviewees), including blends and the use of more alcohol-tolerant yeast strains as well as dealcoholization in hot year and increased fermentation in dry year.

Switching to a long-run perspective, the large majority of interviewees (87%) think that targeted investments will be needed to reduce the impacts of climate change on wine production in the future. The expected investments include an irrigation system to cope with drought (46%), insurances against natural disasters (43%), while 32% of them consider it necessary to attend training courses to keep track of progress and new technologies. Moreover, various producers intend to introduce changes in the following activities:

- harvesting dates - testing new, earlier varieties, early harvesting for acidity increase (48%);
- soil management practices, such as drainage, inertia and treatment under row, milling reduction and increased fertilization (43%);
- pruning mode, with a shorter and reduced load (27%);
- rootstocks – adopting more resistant vines with less grapes per plant) (23%);
- plant density (16%).

Table 2
Impact of climate change at the agronomic and economic levels in the targeted years (% variation).

	Hot year (2003)	Dry year (2012)	Rainy year (2014)
Yield (ql/ha)	−14	−10	−3
Alcohol content (°, V/V)	+0.8	+0.8	−1.3
Vine growing production costs (€/ha)	+0.2	+0.6	+19.8
Wine making production costs (€/hl)	+4.4	−2.2	+14.6

Despite the adaptation practices implemented by producers, the impacts of climate change on production of Sangiovese over the three reference years are appreciable, entailing a general reduction in yields and an increase in production costs (Table 2). In particular, the decrease in yield occurs in each of the three years considered, with a lower reduction in the rainy year, due to grapes swelling. This phenomenon allowed to reduce yield loss in terms of weight production; however, it also entailed a decrease in alcohol content. As far as production costs (€/ha) are concerned, in the rainy year they increased by about 20% in the vineyard and by 15% in cellar. This is because more phytosanitary treatments in the vineyard and practices in the cellar (e.g. enrichment, bleeding, short maceration, and sulphite addition) are required.

4.2. Results of the cluster analyses

Each of the three clustering procedures carried out considered a different group of drivers affecting farm adaptive capacity to climate change: C1 was based on farm characteristics, C2 was based on farmers' perception on climate change and C3 was based on environmental actions carried out by farmers (Table 3).

As a result of the first clustering procedure based on the characteristics of wine production and wine making farms (C1), three clusters were obtained. The farms in the first cluster (C1.1) are mostly individual farms with vineyards of 1 to 5 ha in a single plot of land. Most of them have no annual employees and harvest manually, selling their products on both national and international markets, but not in large quantities. Farms in cluster C1.2 are small farms that handle manual grape harvesting and have little investment capacity to purchase high technology equipment. They are medium sized, with annual employees and national and international destination markets. These farms are mainly managed by graduated staffs, who follow training and updating courses in 80% of the cases. The farms belonging to the third cluster (C1.3) are generally large, well structured, with parceled vineyards and good financial capacity, considering the presence of employees and equipment for mechanized harvesting.

The second clustering procedure based on producer perception of climate change (C2) divided the sample in two main clusters: the first one (C2.1), with a clearer perception of the phenomenon than those in the second cluster (C2.2). The

Table 3
Structure and results the three clustering procedures.

Drivers influencing adaptive capacity	Clustering variables	Clusters obtained (n. of farms)
C.1 Farm characteristics	• Organizational form • Annual employees • Mechanized harvesting • Planted area • Market • Vineyard fragmentation	C1.1 Small farms with a single vineyard and no mechanized harvest (n=15) C1.2 Medium sized farms with annual employees and national and international destination markets (n=24) C1.3 Large farms with parceled vineyards and mechanized harvesting (n=17)
C.2 Interviewees' perception of climate change	• Use of forecasting models • Awareness of different sensitivity of grapes • Knowledge of the environmental factors that affects the wine production	C2.1 Producers with a clear perception of climate change (n=35) C2.2 Producers with a vague perception of climate change (n=21)
C.3 Environmental actions	• Sustainability practices • Environmental label (ISO, Organic, etc.)	C3.1 High environmental attitude (n=37) C3.2 Low environmental attitude (n=19)

producers in the first cluster are more sensitive and aware of the issue. They are older and therefore, have more personal experience with climatic trends in recent years; they are also mostly educated, with a degree in 43% of the cases; on the other hand, 55% of the producers in C2.2 have a high school degree.

As for the analysis based on the environmental actions (C.3), it is possible to distinguish a more numerous group of farms with a "high environmental attitude" (i.e. 37 certified and organic farms) belonging to C.3.1 and a smaller group of non-certified and non-biological farms belonging to cluster C.3.1 (19 farms).

4.3. Interaction between variables

The BN constructed points out some general trends in the sample surveyed and allows to assess the three research hypotheses formulated (Fig. 3). Further details concerning each research hypothesis formulated can be obtained from the following Tables 4, 5 and 6.

H1. Do farm characteristics and producer perceptions of climate change affect farm adaptive capacity acting on the possibility to implement reactive adaptation practices?

Based on the BN results (Table 4), as well as on the Chi-squared tests performed (all p-values are < 0.001), farms in each of the three groups obtained in the first cluster analysis increased the number of practices adopted in all the three years considered, as compared to a standard year.

Further, we observe that farms with parceled vineyards and mechanized harvesting are more likely to implement more reactive adaptation practices, in particular in dry and rainy years. This aspect may relate to the greater organizational, managerial and financial capacity that differentiates them from smaller firms.

However, it is interesting to note that small firms with a single vineyard and no mechanized harvest, registered a 34% probability of implementing a large number of adaptation practices in hot year, compared to medium (10%) or large farms (19%). A possible explanation for this phenomenon is the need to compensate for the lack of an irrigation system with cultivation practices, soil management, and variation in harvest dates.

Also, the BN showed that climate change perception does not significantly affect the number of adaptation practices that wine growers implement in the short-run. Rather, adaptation practices depend more on the structural features of the farm and on yearly weather. In other words, wine growers react to climate issues by adapting their day-to-day production techniques in a reactive form, regardless of their opinion on climate change.

H2. Do the type and/or number of adaptation practices and environmental actions reduce the negative impacts of climate change?

Based on the results of the BN analysis, some interesting considerations can be drawn concerning the relationships between the typology of the adaptation practices implemented, the availability of resources, and the impacts on farm adaptive capacity. More precisely, appropriate agronomic practices, such as changes in harvesting date, soil and water management, and cultivation practices, seem to play a role in the mitigation of the negative impacts of climate change at the agronomic level.

However, we must acknowledge that overall the BN did not return decisive results. Most likely, this is because of the wide

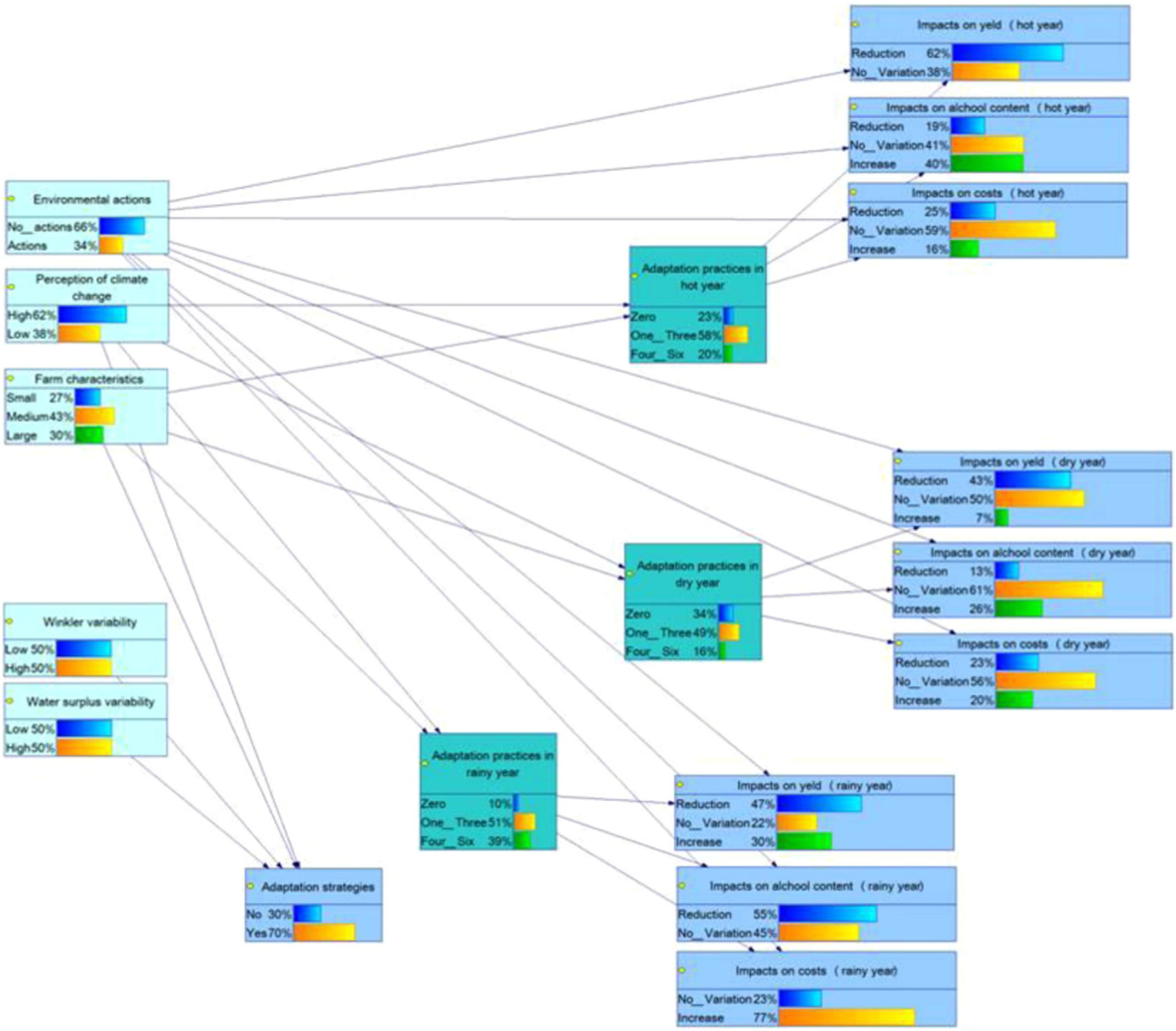

Fig. 3. Bayesian Network results.

Table 4
Farm characteristics and number of adaptation practices in selected years[*].

Drivers	N. of practices in the hot year (2003)			N. of practices in the dry year (2012)			N. of practices in the rainy year (2014)		
	0	1–3	4–6	0	1–3	4–6	0	1–3	4–6
C1.1 Small farms with a single vineyard and no mechanized harvest	27%	39%	34%	40%	39%	22%	10%	57%	33%
C1.2 Medium sized farms with annual employees and national and international destination markets	34%	56%	10%	42%	52%	6%	15%	56%	29%
C1.3 Large farms with parceled vineyards and mechanized harvesting	3%	77%	19%	19%	55%	25%	3%	40%	56%

[*]Full node state descriptions are reported in Table A1.

Table 5
Number of adaptation practices and estimated impacts of climate change (% variation)*.

Drivers		Impact on yield			Impact on alcohol content			Impact on costs		
		Lower	No var.	Increase	Lower	No var.	Increase	Lower	No var.	Increase
N. of practices in hot year	0	53%	47%	0%	45%	40%	15%	45%	40%	15%
	1–3	64%	36%	0%	12%	47%	42%	21%	62%	17%
	4–6	68%	32%	0%	8%	25%	67%	13%	74%	13%
N. of practices in dry year	0	21%	74%	5%	20%	63%	17%	20%	64%	17%
	1–3	53%	41%	6%	8%	56%	36%	21%	57%	21%
	4–6	57%	30%	13%	13%	69%	19%	37%	37%	26%
N. of practices in rainy year	0	55%	22%	23%	66%	34%	0%	0%	50%	50%
	1–3	56%	22%	22%	42%	58%	0%	0%	26%	74%
	4–6	34%	23%	44%	70%	30%	0%	0%	13%	87%

*Full node state descriptions are reported in Table A1.

Table 6
Drivers affecting long-term adaptation strategies*.

Drivers		Adaptation strategies	
		No	Yes
C.1 Farm characteristics	C1.1 Small farms with a single vineyard and no mechanized harvest	31%	69%
	C1.2 Medium sized farms with annual employees and national and international destination markets	34%	66%
	C1.3 Large farms with parceled vineyards and mechanized harvesting	25%	75%
C.2 Perception of climate change	C2.1 Producers with a clear perception of climate change	17%	83%
	C2.2 Producers with a vague perception of climate change	52%	48%
Winkler variability	Low	36%	64%
	High	25%	75%
Water surplus variability	Low	32%	68%
	High	29%	71%

*Full node state descriptions are reported in Table A1.

variety of practices registered and the large number of cause-effect relationships entailed, compared to the limited empirical evidence available.

Thus, in order to account for the effort made by farmers to limit the impact of extreme climatic conditions, the analysis was repeated considering the number of practices adopted (Table 5). However, also the number of adaptation practices do not seem to affect grapevine yields, wine alcohol content or production costs, since the Chi-squared tests did not disclose any statistically significant relationship. Again, this is most likely due to the limited number of observations (the Chi-squared test may not be valid since more than 20% of the cells if the sub table cell count is less than 5).

Besides the considerations made on the type and number of adaptation practices, some interesting relationships can be spotted between the implementation of environmental actions and the impacts of climate change. In particular we observe that farmers who carry out environmental actions have a higher probability to register no variation in yield, alcohol content and cost in the hot year. The same relationship is not evident in the dry and rainy years, when the difference between values is not very strong. This unclear result may be explained by the fact that environmental actions (in particular environmental and process certification) can add value to the final product in terms of image of the product and of the farm, but they are not related to the technical, managerial and financial capacity to cope with climate change impact. Only if environmental concerns translate into strategic actions (such as increased investments in research and technological development or changes in product and process design) can these represent a competitive advantage by providing greater capability for adaptation to climate change.

H3. Do farm characteristics, producer perception of climate change and climatic variability experienced at the farm level affect the intention to implement adaptation strategies?

In the long run, climatic challenges entail the adoption of management and adaptation strategies (new rootstocks, new varieties, irrigation systems, mechanized harvesting, etc.), if producers wish to maintain a sustainable competitive advantage.

Indeed, farmers in each of the group considered showed a high probability to adopt adaptation strategies to safeguard production and to ensure good business performance in the future (Table 6).

Moreover, while producer perception on climate change may not significantly affect the number of adaptation reactive practices, the BN shows an evident difference for the long-term strategies: producers with a clear perception intend to implement long-term strategies (83% of probability, against 48% for farmers with a vague perception on climate change perception).

These results are confirmed by the Chi-squared tests performed (all p-values are < 0.001).

5. Conclusions

The study conducted assessed the technical and economic impacts of climate change on wine growing and wine making firms producing Sangiovese in the Emilia-Romagna region, showing that adaptation practices and strategies can largely reduce the potential negative impacts of climate change and climate variability on wine production and farmer income.

Overall, the company characteristics, the perception of the producer of climate change and local climate variability are found to be the main factors affecting farm adaptive capacity.

Specifically, we found that wine growers react to climate issues by adapting their day-to-day production techniques in a reactive form, regardless of their opinion on climate change. Moreover, producer behavior and intention to implement reactive practices and strategies are largely dependent on structural and technical farm characteristics, producer perception on climate change and climate variability.

As a further consideration, the type of agronomic practices and resource (water) availability seem to have a potential impact on yields, wine alcohol content and production costs. In fact, appropriate agronomic practices, such as changes in harvesting date, soil and water management, and cultivation practices, may reduce drastically the negative impacts on yields, but higher costs may occur, especially due to the intensification of plant protection treatments. However, the analysis performed were not really decisive in this respect, and further investigations are necessary.

The study also pointed out that producers who are aware of the ongoing changes in climatic conditions are more likely to implement adaptation strategies suitable to sustain profitability in the long-run.

Overall we argue that there is a need to improve the level of knowledge, information and research on innovative management systems and adaptation options and to provide incentives, specific insurance systems and public investments for the adoption of adaptation and mitigation measures as part of the local supporting policies.

The main implications of the results obtained concern farm strategic orientation and policy support in order to safeguard company performance levels, in a context of changed competitive conditions. Specifically, the study pointed out the need to improve and strengthen the daily climate forecasts at local level, (preferably at the vineyard level), rather than the construction of complex global and long-term forecast models. Furthermore, in the future, farmers will have to adopt appropriate insurance instruments and invest in cost-effective irrigation systems to cope with drought. They should also further increase the practice of mechanization of wine grape harvesting, that is useful for the timeliness and productivity of operations, allowing to speed up the collection and reduce costs. Possible modifications in the PDO production specifications may also be considered especially because of the excessive restrictions in a context of changes both in the climate and in the market.

At the same time, farmers should be supported by appropriate political and financial instruments to implement new actions to adapt and mitigate climate change. For instance, rural development programs, in addition to greening actions, could support company modernization and the strengthening of the research and development component useful for the implementation of innovative adaptation technologies.

The major limitations of the present study relate to the size of the sample surveyed and the limited number of variables considered. Future research should validate and expand the approach proposed by means of a larger survey and including additional relevant factors that can affect the relationships assessed, such as soil related data as a key factor defining the sensitivity of the vineyard to extreme drought or extreme rainfall. The model could also be expanded by calculating the phenological windows of the vine plant, not on the basis of the average annual values for each vineyard, but on the specific actual data from each year. Additionally, in future research, data from other farms and geographic areas can be used to test the BN model with information that was not used in this work, to characterize causal-effects relationships (i.e. CPTs). BNs, in fact, have the possibility to be quickly updated as new information becomes available.

Acknowledgments

We gratefully acknowledge the valuable contribution and scientific advice of the experts of the Regional Agency for the Protection of the Environment Energy (ARPAE), those at the Crop Production Research Center (CRPV), and the Emilia-Romagna Regional Authority for the support in the agrometeorological analysis.

Conflict of interest

None.

Appendix

See Table A1 here.

Table A1
Assumptions behind the structure of the BN.

Variables	State	Source	Assumptions for the BN
Farm characteristics	– Small – Medium – Large	Questionnaire	– Mostly individual farms with vineyards of 1 to 5 ha in a single plot of land. Most of them have no annual employees and harvest manually, selling their products on both national and international markets (C1.1) – Medium sized farms, with annual employees and national and international destination markets (C1.2) – Large farms with parceled vineyards and mechanized harvest (C1.3)
Perception of climate change	– High – Low	Questionnaire	– Clear perception of climate change (C2.1) – Vague perception of climate change (C2.2)
Environmental actions	– Non-certified – Certified	Questionnaire	– Farms which do not have and do not intend to convert to organic production (C3.1) – Organic farms undergoing conversion from traditional to organic production farms (C3.2)
Winkler variability	– High – Low	Climate data (ARPAE)	Variable based on Winkler index deviation values, calculated for the period 2001–2016, above (High) or below (Low) the median calculated for all the vineyards surveyed
Water surplus variability	– High – Low	Climate data (ARPAE)	Variable based on water surplus standard deviation values calculated for the grapes ripening phase (September - October) for the period 2001–2016, above (High) or below (Low) the median calculated for all the vineyards surveyed
Adaptation practices	– Zero – One-Three – Four-Six	Questionnaire	Aggregated values of the number of practices implemented by farmers over the year.
Impacts on yield	– Reduction – No variation – Increase	Questionnaire	– %variation – <0% variation$=0$ – % variation >0
Impacts on alcohol content	– Reduction – No variation – Increase	Questionnaire	– %variation <0 – % variation$=0$ – % variation >0
Impact on costs	– Reduction – No variation – Increase	Questionnaire	– %variation <0 – % variation$=0$ – % variation >0
Adaptation strategies	– Yes – No	Questionnaire	– respondents who foresee the implementation of long-term strategies to adapt production to the future – respondents who do not foresee the implementation of long-term strategies to adapt to production in the future

References

Ajzen, I., 1991. The theory of planned behavior. Organ Behav. Hum. Decis. Process 50, 179–211. http://dx.doi.org/10.1016/0749-5978(91)90020-T.

Anderson, K., 2017. How might climate changes and preference changes affect the competitiveness of the world's wine regions?. Wine Econ. Policy 6 (1), 23–27. http://dx.doi.org/10.1016/j.wep.2016.12.001.

Anderson, K., Findlay, C., Fuentes, S., Tyerman, S., 2008. Viticulture, wine and climate change. Garnaut Clim. Chang. Rev. 22.

Antle, J.M., Capalbo, S.M., Elliott, E.T., Paustian, K.H., 2004. Adaptation, spatial heterogeneity, and the vulnerability of agricultural systems to climate change and CO_2 fertilization: an integrated assessment approach. Clim. Chang. 64, 289–315. http://dx.doi.org/10.1023/B:CLIM.0000025748.49738.93.

Antolini, G., Auteri, L., Pavan, V., et al., 2016. A daily high-resolution gridded climatic data set for Emilia-Romagna, Italy, during 1961–2010. Int. J. Climatol. 36, 1970–1986. http://dx.doi.org/10.1002/joc.4473.

Artikov, I., Hoffman, S.J., Lynne, G.D., et al., 2006. Understanding the influence of climate forecasts on farmer decisions as planned behavior*. J. Appl. Meteorol. Climatol. 45, 1202–1214. http://dx.doi.org/10.1175/JAM2415.1.

Aragón-Correa, J.A., Hurtado-Torres, N., Sharma, S., García-Morales, V.J., 2008. Environmental strategy and performance in small firms: a resource-based perspective. J. Environ. Manag. 86 (1), 88–103.

Ashenfelter, Orley, Storchmann, K., 2014. 'Wine and climate change'. Am. Assoc. Wine Econ. 152.

Banerjee, S.B., 2002. Corporate environmentalism: the construct and its measurement. J. Bus. Res. 55 (3), 177–191.

Belliveau, S., Smit, B., Bradshaw, B., 2006. Multiple exposures and dynamic vulnerability: evidence from the grape industry in the Okanagan Valley, Canada. Glob. Environ. Chang 16, 364–378. http://dx.doi.org/10.1016/j.gloenvcha.2006.03.003.

Below, T.B., Mutabazi, K.D., Kirschke, D., et al., 2012. Can farmers' adaptation to climate change be explained by socio-economic household-level variables?. Glob. Environ. Chang. 22, 223–235. http://dx.doi.org/10.1016/j.gloenvcha.2011.11.012.

Bernetti, I., Menghini, S., Marinelli, N., Sacchelli, S., Sottini, V.A., 2012. Assessment of climate change impact on viticulture: economic evaluations and adaptation strategies analysis for the Tuscan wine sector. Wine Econ. Policy *1* (1), 73–86.

Bromley, J., Jackson, N.A., Clymer, O.J., et al., 2005. The use of Hugin® to develop Bayesian networks as an aid to integrated water resource planning. Environ. Model Softw. 20, 231–242. http://dx.doi.org/10.1016/j.envsoft.2003.12.021.

Broomell, S.B., Budescu, D.V., 2015. Por H., Personal experience with climate change predicts intentions to act. Global Environmental Change 32, 67–73.

Busuioc, A., Tomozeiub, R., Cacciamani, C., 2008. Statistical downscaling model based on canonical correlation analysis for winter extreme precipitation events in the Emilia-Romagna region. Int. J. Climatol.http://dxdoi.org/10.1002/joc.1547.

Camanzi, L., Alikadic, A., Compagnoni, L., Merloni, E., 2017. The impact of greenhouse gas emissions in the EU food chain: a quantitative and economic assessment using an environmentally extended input-output approach. J. Clean. Prod. 157, 168–176. http://dx.doi.org/10.1016/J.JCLEPRO.2017.04.118.

Cuerva, M.C., Triguero-Cano, Á., Córcoles, D., 2014. Drivers of green and non-green innovation: empirical evidence in Low-Tech SMEs. J. Clean. Prod. 68, 104–113. http://dx.doi.org/10.1016/j.jclepro.2013.10.049.

Deressa, T.T., Hassan, R.M., Ringler, C., et al., 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Glob. Environ. Chang. 19, 248–255. http://dx.doi.org/10.1016/j.gloenvcha.2009.01.002.

Fraga, H., Malheiro, A.C., Moutinho-Pereira, J., Santos, J.A., 2012. Climate change projections for the portuguese viticulture using a multi-model ensemble. Ciencia e Tecnica Vitivinicola 27 (1), 39–48.

Fraj-Andrés, E., Martinez-Salinas, E., Matute-Vallejo, J., 2009. A multidimensional approach to the influence of environmental marketing and orientation on the firm's organizational performance. J. Bus. Ethics 88, 263–286. http://dx.doi.org/10.1007/s10551-008-9962-2.

Gbetibouo, G.A., 2009. Understanding Farmers' Perceptions and Adaptations to Climate Change and Variability. IFPRI, 36.

Genç, K.Y., 2013. Natural environment as a strategic issue for firms: theoretical perspectives. Procedia - Soc. Behav. Sci. 99, 143–153 http://dx.doi.org/10.1016/j.sbspro.2013.10.480.

Gladstones J., 1992. Viticulture and environment. Winetitles.

Graedel, T.E., Allenby, B.R., 2002. Hierarchical metrics for sustainability. Environ. Qual. Manag. 12, 21–30. http://dx.doi.org/10.1002/tqem.10060.

Hadjimanolis, A., 2000. A resource-based view of innovativeness in small firms. Technol. Anal. Strat. Manag. 12 (2), 263–281.

Hart, S.L., Dowell, G., 2011. A natural-resource-based view of the firm: fifteen years after. J. Manag. 37 (5), 1464–1479. http://dx.doi.org/10.1177/0149206310390219.

Hart O., 1995. Firms, Contracts, and Financial Structure - Oliver Hart - Google Libri.

Hinkel, J., 2011. "Indicators of vulnerability and adaptive capacity": Towards a clarification of the science–policy interface. Global Environmental Change 21 (1), 198–208.

Hu, Q., Zillig, L.M.P., Lynne, G.D., et al., 2006. Understanding farmer's forecast use from their beliefs, values, social norms, and perceived obstacles. J. Appl. Meteorol. Climatol. 45, 1190–1201. http://dx.doi.org/10.1175/JAM2414.1.

ISTAT, 2010. Censimento Agricoltura 2010. 〈http://dati-censimentoagricoltura.istat.it/Index.aspx〉.(Accessed 21 March 2017).

Jones, G., Schultz, H., 2016. Climate change and emerging cool climate wine regions. Wine Vitic. J. 31, 51–53.

Lereboullet, A., Bardsley, D., Beltrando, G., 2013. Assessing Vulnerability and Framing Adaptive Options of Two Mediterranean Wine Growing Regions Facing Climate Change: Roussillon (France) and McLaren. EchoGéo.

López-Gamero, M.D., Molina-Azorín, J.F., Claver-Cortés, E., 2009. The whole relationship between environmental variables and firm performance: competitive advantage and firm resources as mediator variables. J. Environ. Manag. 90 (10), 3110–3121. http://dx.doi.org/10.1016/j.jenvman.2009.05.007.

Michalisin, M.D., Stinchfield, B.T., 2010. Climate change strategies and firm performance: an empirical investigation of the natural resource-based view of the firm. J. Bus. Strateg. 27 (2), 123–149.

Mozell, M.R., Thach, L., 2014. The impact of climate change on the global wine industry: challenges & solutions. Wine Econ. Policy 3 (2), 81–89. http://dx.doi.org/10.1016/j.wep.2014.08.001.

Nicholas, K.A., Durham, W.H., 2012. Farm-scale adaptation and vulnerability to environmental stresses: insights from winegrowing in Northern California. Glob. Environ. Chang. 22, 483–494. http://dx.doi.org/10.1016/j.gloenvcha.2012.01.001.

Niles, M.T., Mueller, N.D., 2016. Farmer perceptions of climate change: associations with observed temperature and precipitation trends, irrigation, and climate beliefs. Glob. Environ. Chang. 39, 133–142 http://dx.doi.org/10.1016/j.gloenvcha.2016.05.002.

O'Brien, K., Leichenko, R., Kelkar, U., et al., 2004. Mapping vulnerability to multiple stressors: climate change and globalization in India. Glob. Environ. Chang. 14, 303–313. http://dx.doi.org/10.1016/j.gloenvcha.2004.01.001.

Olesen, J.E., Trnka, M., Kersebaum, K.C., et al., 2011. Impacts and adaptation of European crop production systems to climate change. Eur. J. Agron. 34, 96–112. http://dx.doi.org/10.1016/j.eja.2010.11.003.

Orlitzky, M., Schmidt, F.L., Rynes, S.L., 2003. Corporate social and financial performance: a meta-analysis. Organ. Stud. 24, 403–441 http://dx.doi.org/10.1177/0170840603024003910.

Pouder, R., St. John, C.H., 1996. Hot spots and blind spots: geographical clusters of firms and innovation. Acad. Manag. Rev. 21, 1192–1225. http://dx.doi.org/10.5465/AMR.1996.9704071867.

Ramos, M., Jones, G., Martínez-Casasnovas, J., 2008. Structure and trends in climate parameters affecting winegrape production in northeast Spain. Clim. Res. 38, 1–15. http://dx.doi.org/10.3354/cr00759.

Reidsma, P., Ewert, F., Lansink, A.O., Leemans, R., 2010. Adaptation to climate change and climate variability in European agriculture: the importance of farm level responses. Eur. J. Agron. 32, 91–102. http://dx.doi.org/10.1016/j.eja.2009.06.003.

Reidsma, P., Ewert, F., Oude Lansink, A., Leemans, R., 2009. Vulnerability and adaptation of European farmers: a multi-level analysis of yield and income responses to climate variability. Reg. Environ. Chang. 9, 25–40. http://dx.doi.org/10.1007/s10113-008-0059-3.

Richards, R., Sanó, M., Roiko, A., Carter, R.W., Bussey, M., Matthews, J., Smith, T.F., 2013. Bayesian belief modeling of climate change impacts for informing regional adaptation options. Environmental Modelling & Software 44, 113–121.

Ruml, M., Vuković, A., Vujadinović, M., et al., 2012. On the use of regional climate models: implications of climate change for viticulture in Serbia. Agric. Meteorol. 158–159, 53–62. http://dx.doi.org/10.1016/j.agrformet.2012.02.004.

Sacchelli, S., Fabbrizzi, S., Menghini, S., 2016. Climate change effects and adaptation strategies in the wine sector: a quantitative literature review. Wine Econ. Policy 5 (2), 114–126. http://dx.doi.org/10.1016/j.wep.2016.08.001.

Smit, B., Wandel, J., 2006. Adaptation, adaptive capacity and vulnerability. Glob. Environ. Chang. 16, 282–292. http://dx.doi.org/10.1016/j.gloenvcha.2006.03.008.

Smith, P., Martino, D., Cai, Z., et al., 2007. Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. Agric. Ecosyst. Environ. 118, 6–28. http://dx.doi.org/10.1016/j.agee.2006.06.006.

Spence, A., Poortinga, W., Pidgeon, N., 2012. The Psychological Distance of Climate Change. Risk Analysis 32, 957–972. http://dx.doi.org/10.1111/j.1539-6924.2011.01695.x.

Stock, M., Gerstengarbe, F.W., Kartschall, T., Werner, P.C., 2005. Reliability of climate change impact assessments for viticulture. Acta Hortic., 29–40. http://dx.doi.org/10.17660/ActaHortic.2005.689.1.

Ticehurst, J.L., Curtis, A., Merritt, W.S., 2011. Using Bayesian Networks to complement conventional analyses to explore landholder management of native vegetation. Environ. Model Softw. 26, 52–65. http://dx.doi.org/10.1016/j.envsoft.2010.03.032.

Urhausen, S., Brienen, S., Kapala, A., Simmer, C., 2011. Climatic conditions and their impact on viticulture in the Upper Moselle region. Clim. Chang. 109, 349–373. http://dx.doi.org/10.1007/s10584-011-0059-z.

van Leeuwen, C., Friant, P., Chone, X., et al., 2004. Influence of climate, soil, and cultivar on terroir. Am. J. Enol. Vitic. 55, 207–217.

Vincent, K., 2007. Uncertainty in adaptive capacity and the importance of scale. Glob. Environ. Chang. 17, 12–24. http://dx.doi.org/10.1016/j.gloenvcha.2006.11.009.