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Climate change effects and adaptation strategies in the wine sector: a quantitative literature review

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Abstract

This paper presents a quantitative literature review focusing on how scientific research analysed climate change impact on wine chain as well as potential adaptation strategies. The work is based on content analysis and text mining and takes into account researches from 1990 to 2015. A particular emphasis was given to the evaluation of suggested or implemented adaptation strategies at both global and national levels. Data were analysed using cluster analysis, multidimensional scaling and specificity evaluation. Results show that the study of climate change impacts on the wine sector is a recently emerging research topic. Adaptation strategies have not yet been explored thoroughly in the literature, and in-depth uncertainty quantification is also needed. Finally, additional research gaps and potential future issues are suggested.

Keywords: Climatic impact; Content analysis; Multiscale review

Contents

1. Introduction

The impact of climate change (CC) on the environmental and rural sectors has been widely discussed and examined in recent decades. Several documents and reports have been published to increase understanding and develop potential strategies to overcome negative effects of this phenomenon (see e.g., IPCC et al., 2014). Despite increased interest about that topic, knowledge on CC effects, mitigation, adaptation and vulnerability is fragmented due to the peculiarities of different study areas and uncertainty in model forecasts. These topics are particularly relevant for the wine sector because the qualitative characteristics of its final products are not only the results of *terroir* – which expresses the relationship among vines, ecopedology, the cultivation process and climatic variables – but also an expression of cultural and socio-economic parameters (community parameters). Community parameters determine the diversity and originality of the wines

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produced in a certain area because of firms can incorporate into their businesses a sense of land and place. It allows the firm to deliver a product that will be more competitive and that can be sold at a premium price (Elaydi and McLaughlin, 2012).

The analysis of CC impact on the wine sector highlights the increased interest in this subject for both potential trends and impact analysis on the production chain and its products (Mozell and Thach, 2014). Among the most significant studies have focused on environmental aspects, including potential variation in cultivar distribution (Schultz and Jones, 2010; Fraga et al., 2012; Ruml et al., 2012), variation of vine productivity (Bindi et al., 1996; Holland and Smit, 2010; Schultz and Jones, 2010), the spread of pests and plant infections (Jones et al., 2005; Stock et al., 2005; Caffarra et al., 2012) and the impact on phenological activity (Schultz, 2000; Webb et al., 2007). Additional studies have concentrated on specific (Hadarits et al., 2010; Keller, 2010, Galletto et al., 2014) or optimised (Zhu et al., 2016) intervention strategies to cope with negative effects of CC as well as on economic damage (Moriondo et al., 2011; Bernetti et al., 2012; De Salvo et al., 2013). The social dimension of CC affecting the wine chain has mainly been determined through the evaluation of local stakeholders' perceptions (Hadarits et al., 2010; Alonso and O'Neill, 2011), as well as through socio-ecological approaches (Battaglini et al., 2009). More insights regarding the influence of CC on wine systems were proposed in Lereboullet et al. (2013) through the application of mixed-methods. In this last paper, the authors combined multiple methodologies to model the wine sector as a complex system in an integrated perspective for French and Australian case studies. Particular research outputs highlighted a potential shifts of wine regions in response to CC. For example Moriondo et al. (2013) confirmed that the shifts to higher elevations as well as latitudes of European areas that are potentially suitable to the cultivation of grapevines, can appear. The application of ARPEGE model in Champagne region revealed how the impact of CC deal to a decrease in extreme low temperatures during bud break and an increase in extreme high temperatures in summer, associated with more frequent heat waves during ripening with adverse consequences on grapevines phenology (Briche et al., 2014). The negative effects of CC on socio-economic variables were emphasised by Pomarici and Seccia (2016) for both short and long term forecast. In a recent paper of Galbreath et al. (2016) attention was paid to the drivers of climate change innovations and the effects of these innovations on firms of the South Australian wine cluster. By the application of structural equation modelling the authors stress how climate change innovations seems to stimulate knowledge exchanges between firms as well as firm performance and reduction in greenhouse gases.

The above-mentioned literature shows both methodological and geographic variability in CC impact analysis on winemaking. In this framework, integrated and state-of-the-art research methodologies that are able to support decision-makers in adaptation as well as mitigation strategies from local to international levels are recommended (Tripathi et al., 2016). This means that i) CC effects on wine sector have to be analysed in a holistic perspective that takes into account all of the above mentioned aspects and that ii) literature reviews must furnish "user-friendly" results to highlight current research gaps and to drive future research.

A useful technique to attain the above objectives is represented by quantitative categorisation of the literature. Focusing on CC, Wei et al. (2015) applied a bibliometric method to research modelling in the field of climate policy. A meta-analysis to classify CC-related studies according to adaptation as well as the regional and thematic context of publications was developed in Hofmann et al. (2011). In a quantitative analysis implemented by Pasgaard and Strange (2013), the distribution of CC research and the potential causes of this distribution were investigated. The global scientific output of CC research patterns, tendencies and methods were analysed in Li et al. (2011).

Among quantitative techniques, text mining allows compressing the information of large texts, which allows for more straightforward analysis and understanding of complex data (Benzécri, 1992; Ogiela, 2013). Text mining techniques are applied to obtain automated information from textual data sources (Berry and Kogan, 2010). Since the 1960s, interest in content analysis has been widening, and it now includes not only stylometric studies on books but also linguistic data analysis from different sources, including focus groups (Debucquet et al., 2012; Mazzonetto and Fiates, 2014), structured and semi-structured interviews (Nicolini et al., 2010; Parr et al., 2011; Bories et al., 2014), scientific discourses (Tonta and Darvish, 2010; Plumecocq, 2014), news articles (Rivera et al., 2014) and media publications (Sengers et al., 2010), with a particular emphasis on web pages (White, 2013) and blogs (Fløttum et al., 2014).

Application of text mining in the wine sector has mainly concentrated on marketing topics. For example, Sauvageot et al. (2006) defined a lexicalisation of experts' elicitation regarding different Chardonnay wines. Sallis et al. (2008) use a Kohonen self-organising map based on text mining to analyse wine taster comments and their relation with wine sensory data. Maizza et al. (2014) used a text mining approach to create an effective web communication activity calibrated for wine tourism destinations. Another work concentrated on text mining application in food security for the identification of emerging risks (van de Brug et al., 2014). Finally, Shanmuganathan and Salliset (2009) applied web-based descriptions made by sommeliers in a text mining model (WEBSOM) to investigated wine quality perception in case of climate variation.

Given this previous research, the innovation of the present work with respect to the available quantitative literature analysis is the use of a text mining approach for CC impact evaluation on the wine chain, as well as analysis of developed studies regarding potential adaptation strategies. Methodological insights of the work are reported in Section 2. Chapter 3 defines the main results. In the "Discussion and conclusion" section, potential applications of results and future research trends regarding CC effects on wine sector are highlighted.

2. Methodology

A quantitative literature review was developed based on a text corpus derived from title, abstract and keywords of papers extracted from the Web of Science (WoS) and Scopus advanced search databases. Extracted papers refer to the period 1990–2015 and represent the total amount of published works indexed in WoS and Scopus in that temporal range. These platforms cover a wide variety of scientific journals, monographs and symposia published in series (Goodman and Deis, 2007). A prior study by Gavel and Iselid (2008) highlighted the presence of a particular traditional overlap for WoS and Scopus (46%). This overlap is defined as "the intersection (journal titles or articles covered in both databases) divided by the union (journal titles or articles covered in either database)" (Gavel and Iselid, 2008; p. 9). Therefore, the extraction of unique titles present in both collections was necessary.

Three different extraction (classes) were carried out in order to develop a text mining analysis with an increasing level of detail. The first class (or Topic 1) covers the general subject "climate change". In the second class, (Topic 2) "adaptation strategies" were introduced. Finally, the third category (Topic 3) focuses on adaptation strategies related to CC effects for specific nations. This last class includes an evaluation of ten countries chosen from the major world producers of wine – in quantitative terms – in the year 2015, i.e., Italy, France, Spain, the United States, Argentina, Chile, Australia, South Africa, China and Germany (OIV, 2015). The scripts used for extraction of the three corpus, which are derived from a partial modification and re-calibration of scripts used in Schmidt et al. (2013), are reported in Table 1.

The importance of different Topics – (1, 2 and 3) – related to wine chain with respect to the analysis of the same topic in the whole agricultural sector was also computed. This assessment was calculated according to Eq. 1.

$$\%_{Topic,x} = \frac{T_{Topic,x}}{T_{Gen,x}} \tag{1}$$

where $T_{Topic,x}$ is the number of scientific works related to Topic x, $T_{Gen,x}$ is the number of scientific works concerning Topic x and referred to the whole agricultural sector.

Total number of scientific texts $T_{Topic,x}$ and $T_{Gen,x}$ were calculated as in Eqs. 2 and 3, respectively:

$$T_{Topic,x} = E_{Topic,x} \cdot (1 - 0.5 \cdot \gamma) \tag{2}$$

$$T_{Gen,x} = E_{Gen,x} \cdot (1 - 0.5 \cdot \gamma) \tag{3}$$

where $E_{Topic,x}$ and $E_{Gen,x}$ are the number of paper extracted from WoS and Scopus databases using the scripts found in Tables 1 and 2, respectively; γ is the traditional overlap between WoS and Scopus platforms (Gavel and Iselid, 2008).

Text mining was performed by means of the software T-Lab (www.tlab.it), a tool based on a lexicometric approach (Bolasco, 1999). The extracted texts were imported as .txt files and were pre-processed to improve and prepare the text for the following analysis. Disambiguation, lemmatisation and lexicalisation were all performed. Disambiguation attempts to resolve ambiguous cases related to words with the same graphic form but different meanings. In lemmatisation, words with the same form (root) or similar meaning are encoded in a new form that sums occurrences (e.g., "sustainable/sustainability"). Lexicalisation allows users to trace repeated segments back to a single form (e.g., from "climate change" to "climate_change"). Furthermore, the corpus of text was segmented into elementary contexts embodied, in our case, by paragraphs.

Analyses concerning Topic 1 were subdivided into two steps. First, a quantitative trend representing the number of occurrences for scientific texts from 1990 to 2015 regarding the analysis of CC on the wine sector was performed. Next, an in-depth evaluation was implemented using cluster analysis to explore the main categories of arguments considered in these studies. Cluster analysis was based on a bisecting k-means algorithm (Steinbach et al., 2000) to partition the data into clusters.

The introduction of the "adaptation strategies" lemma (Topic 2) led to a reduction of the number of scientific papers with respect to Topic 1. These were investigated by means of a multidimensional scaling analysis (MDS), which allows users to graphically represent the relationships among lemmas through the use of square similarity matrices. The input matrices used for MDS contain dissimilarity values – distances – computed by means of cosine association index. The degree of correspondence between an MDS map and matrices is measured through either a stress function or Sammon's method (Sammon, 1969). Sammon's algorithm permits users to reduce a high-dimensional space represented by similarity matrices to a low dimensional space (MDS map). Sammon's algorithm minimises the Sammon's error (SE), which is computed using Eq. (4):

$$SE = \frac{1}{\sum\limits_{i<j} d_{i,j}^{\ *}} \cdot \sum_{i<j} \frac{\left(d_{i,j}^{\ *} - d_{i,j}\right)^2}{d_{i,j}^{\ *}} \tag{4}$$

where $d_{i,j}^{*}$ is the distance between lemma i and lemma j in the original space and $d_{i,j}$ is the distance between projection of lemma i and lemma j.

The next stage of our text mining procedure focused on the main adaptation strategies applied in the viticulture sector for nations that are the main producers of wine. The analysis focused on specificity for each nation. Specificity analyses check for lexical units (lemmas) that are typical in a text (in our case the "nation" subset). In other terms specificity analysis allows for depiction of over-used lemmas in respect to other subset, to depict peculiar subject on which literature was focused on. The overuse of typical lexical unit and its significance within a corpus were determined by means of chi-square (Chi^2) tests taking into account observed frequencies of a word in a text as well as expected ones (Greenwood and Nikulin, 1996).

3. Results

The total number of works published worldwide for Topic 1 was 1766. More than half of these were produced within the

Table 1
Scripts for extraction of papers referred to topics 1, 2 and 3 for wine sector.

Topic	Scripts for text extraction
1- Climate change	WoS: TS=(((climat* NEAR/4 (chang* OR catastroph* OR disaster* OR transform* OR adjust* OR trend* OR warm* OR heat* OR cool* OR variab* OR extrem*)) OR ((global* OR earth* OR world* OR international* OR hemisphere*) NEAR/4 (warm* OR heat* OR cool* OR chill*)) OR (temperature* NEAR/4 (global* OR earth* OR world* OR international* OR hemisphere*) NEAR/4 (increas* OR rising* OR rise* OR decreas*)))) AND TS=(wine* OR vine* OR vitic*) Scopus: TITLE-ABS-KEY (((((climat* W/4 (chang* OR catastroph* OR disaster* OR transform* OR adjust* OR trend* OR warm* OR heat* OR cool* OR variab* OR extrem*)) OR ((global* OR earth* OR world* OR international* OR hemisphere*) W/4 (warm* OR heat* OR cool* OR chill*)) OR (temperature* W/4 (increas* OR rising* OR rise* OR decreas*)))) AND (wine* OR vine* OR vitic*)))
2- Climate change – Adaptation	WoS: TS=(((climat* NEAR/4 (chang* OR catastroph* OR disaster* OR transform* OR adjust* OR trend* OR warm* OR heat* OR cool* OR variab* OR extrem*)) OR ((global* OR earth* OR world* OR international* OR hemisphere*) NEAR/4 (warm* OR heat* OR cool* OR chill*)) OR (temperature* NEAR/4 (global* OR earth* OR world* OR international* OR hemisphere*) NEAR/4 (increas* OR rising* OR rise* OR decreas*)))) AND TS=(wine* OR vine* OR vitic*) AND TS=(adapt* OR mitig* OR adjust*) Scopus: TITLE-ABS-KEY (((((climat* W/4 (chang* OR catastroph* OR disaster* OR transform* OR adjust* OR trend* OR warm* OR heat* OR cool* OR variab* OR extrem*)) OR ((global* OR earth* OR world* OR international* OR hemisphere*) W/4 (warm* OR heat* OR cool* OR chill*)) OR (temperature* W/4 (increas* OR rising* OR rise* OR decreas*)))) AND (wine* OR vine* OR vitic*) AND (adapt* OR mitig* OR adjust*)))
3- Climate change – Adaptation – Nation	WoS: TS=(((climat* NEAR/4 (chang* OR catastroph* OR disaster* OR transform* OR adjust* OR trend* OR warm* OR heat* OR cool* OR variab* OR extrem*)) OR ((global* OR earth* OR world* OR international* OR hemisphere*) NEAR/4 (warm* OR heat* OR cool* OR chill*)) OR (temperature* NEAR/4 (global* OR earth* OR world* OR international* OR hemisphere*) NEAR/4 (increas* OR rising* OR rise* OR decreas*)))) AND TS=(wine* OR vine* OR vitic*) AND TS=(adapt* OR mitig* OR adjust*) AND TS=(nation) Scopus: TITLE-ABS-KEY (((((climat* W/4 (chang* OR catastroph* OR disaster* OR transform* OR adjust* OR trend* OR warm* OR heat* OR cool* OR variab* OR extrem*)) OR ((global* OR earth* OR world* OR international* OR hemisphere*) W/4 (warm* OR heat* OR cool* OR chill*)) OR (temperature* W/4 (increas* OR rising* OR rise* OR decreas*)))) AND (wine* OR vine* OR vitic*) AND (adapt* OR mitig* OR adjust*))) AND (TITLE-ABS-KEY (nation))

where: nation= (ital*) OR (france OR french) OR (spain OR spanish) OR (united states OR california* OR american OR usa) OR (argentin*) OR (chile*) OR (australia*) OR (south africa*) OR (chin*) OR (german*).

Table 2
Scripts for extraction of topics 1, 2 and 3 for agricultural sector.

Topic	Scripts for text extraction
1- Climate change	WoS: TS=(((climat* NEAR/4 (chang* OR catastroph* OR disaster* OR transform* OR adjust* OR trend* OR warm* OR heat* OR cool* OR variab* OR extrem*)) OR ((global* OR earth* OR world* OR international* OR hemisphere*) NEAR/4 (warm* OR heat* OR cool* OR chill*)) OR (temperature* NEAR/4 (global* OR earth* OR world* OR international* OR hemisphere*) NEAR/4 (increas* OR rising* OR rise* OR decreas*)))) AND SU=Agriculture Scopus: TITLE-ABS-KEY (((((climat* W/4 (chang* OR catastroph* OR disaster* OR transform* OR adjust* OR trend* OR warm* OR heat* OR cool* OR variab* OR extrem*)) OR ((global* OR earth* OR world* OR international* OR hemisphere*) W/4 (warm* OR heat* OR cool* OR chill*)) OR (temperature* W/4 (increas* OR rising* OR rise* OR decreas*)))))) AND SUBJAREA(AGRI)
2- Climate change – Adaptation	WoS: TS=(((climat* NEAR/4 (chang* OR catastroph* OR disaster* OR transform* OR adjust* OR trend* OR warm* OR heat* OR cool* OR variab* OR extrem*)) OR ((global* OR earth* OR world* OR international* OR hemisphere*) NEAR/4 (warm* OR heat* OR cool* OR chill*)) OR (temperature* NEAR/4 (global* OR earth* OR world* OR international* OR hemisphere*) NEAR/4 (increas* OR rising* OR rise* OR decreas*)))) AND SU=Agriculture AND TS=(adapt* OR mitig* OR adjust*) Scopus: TITLE-ABS-KEY (((((climat* W/4 (chang* OR catastroph* OR disaster* OR transform* OR adjust* OR trend* OR warm* OR heat* OR cool* OR variab* OR extrem*)) OR ((global* OR earth* OR world* OR international* OR hemisphere*) W/4 (warm* OR heat* OR cool* OR chill*)) OR (temperature* W/4 (increas* OR rising* OR rise* OR decreas*)))) AND (adapt* OR mitig* OR adjust*))) AND SUBJAREA(AGRI)
3- Climate change – Adaptation – *Nation*	WoS: TS=(((climat* NEAR/4 (chang* OR catastroph* OR disaster* OR transform* OR adjust* OR trend* OR warm* OR heat* OR cool* OR variab* OR extrem*)) OR ((global* OR earth* OR world* OR international* OR hemisphere*) NEAR/4 (warm* OR heat* OR cool* OR chill*)) OR (temperature* NEAR/4 (global* OR earth* OR world* OR international* OR hemisphere*) NEAR/4 (increas* OR rising* OR rise* OR decreas*)))) AND SU=Agriculture AND TS=(adapt* OR mitig* OR adjust*) AND TS=(nation) Scopus: TITLE-ABS-KEY (((((climat* W/4 (chang* OR catastroph* OR disaster* OR transform* OR adjust* OR trend* OR warm* OR heat* OR cool* OR variab* OR extrem*)) OR ((global* OR earth* OR world* OR international* OR hemisphere*) W/4 (warm* OR heat* OR cool* OR chill*)) OR (temperature* W/4 (increas* OR rising* OR rise* OR decreas*)))) AND (adapt* OR mitig* OR adjust*))) AND (TITLE-ABS-KEY (nation)) AND SUBJAREA(AGRI)

where: nation= (ital*) OR (france OR french) OR (spain OR spanish) OR (united states OR california* OR american OR usa) OR (argentin*) OR (chile*) OR (australia*) OR (south africa*) OR (chin*) OR (german*).

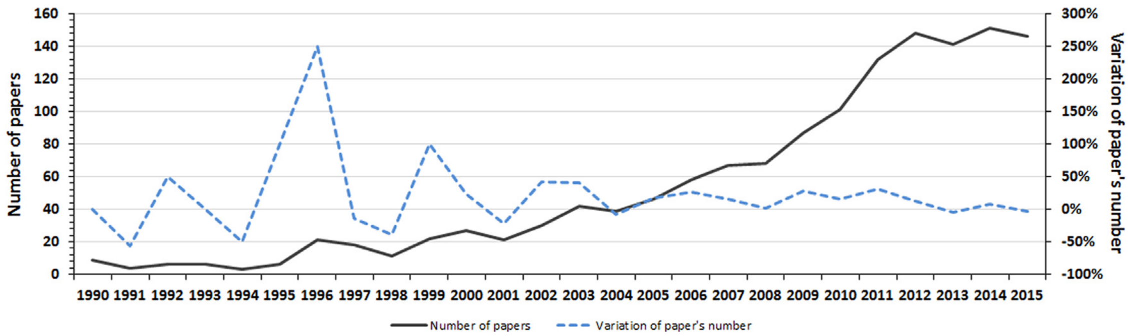

Fig. 1. Total number of produced papers per year and variation of produced papers per year for the period 1990-2015 (data related to Topic 1: Climate change).

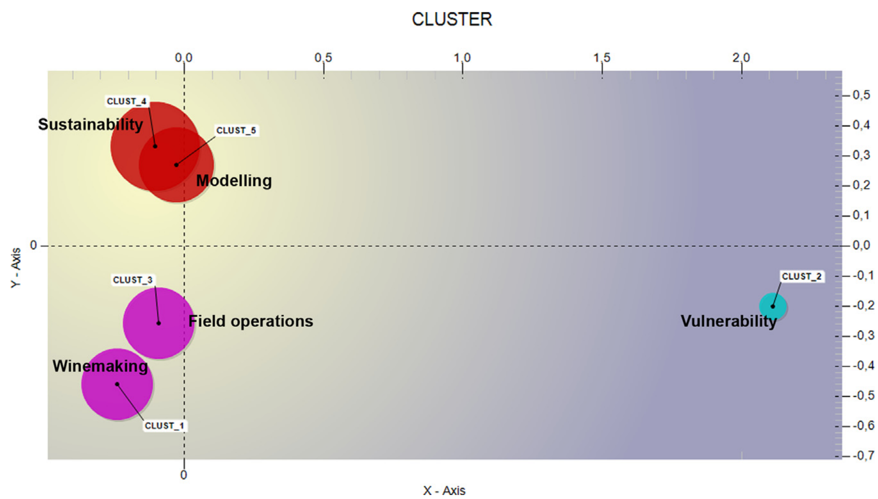

Fig. 2. Clusters for Topic 1 (Climate change).

last five years (Fig. 1). This value corresponds to only 2.2% of total scientific studies published on the issue of "climate change impact" in the agricultural sector. However, it is worth mentioning that viticulture area at the global level only represents about 0.022% of total agricultural surface area (our elaboration on World Bank and OIV data), denoting a strong scientific interest for Topic 1 with respect to climatic effects on the rural sector. Current publishing trends concerning Topic 1 have stabilised in the last five years to approximately 150 new papers per year (Fig. 1).

The main arguments found within Topic 1 were classified into five classes (clusters) in order to maximise between-cluster variance and to minimise within-cluster variance with bisecting k-means algorithm application. Results are shown in Fig. 2 and Table 3.

The most important themes are those found in clusters 1, 3, 4 and 5 as expressed by cluster weights (circle size). Cluster 1 denotes lemmas related to winemaking procedures. Cellar operations that act to minimise field diseases are included here. In particular, they are mainly associated with the fermentation phase but also on products needed in the above process. Cluster 3 highlights how a certain number of manuscripts have concentrated on field operations to overcome the effects of CC. The influence of particular treatments – such as canopy pruning and defoliation or mulching techniques – on fruit as well as phenological activities of vines were included here. As example the strong importance of "berry" or "fruit" lemmas can be interpreted as a specific evaluation of maturation phase and compound concentration related to climatic variability. Cluster 4 contains papers related to general issues in sustainability. The three sustainability pillars (according to the classification of Hacking and Guthrie, 2008) can be ranked in order of importance in environmental, economic and social categories. Ecological parameters seem to have a major influence on research activity (see, e.g., "ecosystem", "habitat", "LCA", "biodiversity" lemmas). Policy and governance issues are also included in this group. The main evidence from cluster 4 seems to be the recent focus on how CC could stress ecosystem services related to wine industry as well as suitable conservation strategies to cope with the above problem. Cluster 5 introduces papers focusing on modelling CC effects on plant phenology and their potential future spatial distribution. In particular climatic data and scenario analysis were applied to forecast temperature, precipitation, and weather conditions able to modify fruit yield, wine quality but also the production process. The last class (cluster 2) collects lemmas belonging to an underrepresented sample. In this group terms related to vulnerability assessment as well as adaptation strategies are reported. One of the major subjects in this category was potential water stress (e.g., due to drought impact) and adaptation strategies for this problem (see, e.g., "rootstock" and "irrigation" terms). In addition, genetic and biotechnological improvement of plants as well as insect diseases were found here.

Table 3
Lemmas for each cluster and their respective significance.

Cluster 1: winemaking (total lemmas: 417)			*Cluster 2: vulnerability (total lemmas: 73)*			*Cluster 3: field operations (total lemmas: 416)*		
Lemma	*Chi²*	*total*	*Lemma*	*Chi²*	*Total*	*Lemma*	*Chi²*	*Total*
Fermentation	30.04	329	Water	10.07	1248	Berry	29.96	679
Yeast	23.57	232	Quality	9.96	732	Leaf	24.80	545
Ethanol	21.79	170	Rootstock	8.84	158	Vine	22.69	985
Compound	19.64	276	Physiology	8.01	60	Fruit	22.13	660
Cell	18.69	246	Grapevine	7.97	2,342	Prune	21.71	222
Acid	18.30	388	Biotechnology	5.58	67	Treatment	20.78	587
Extraction	17.83	137	Ground	5.58	67	Yield	18.98	691
Vinegar	17.58	171	Vulnerability	5.47	51	Canopy	16.76	221
Saccharomyces_cerevisiae	16.90	104	Availability	5.25	92	Bunch	15.70	109
Maceration	16.48	84	Cultivar	5.07	338	Thin	15.36	95
Chemistry	15.37	400	GHG	5.01	48	Stomatal	13.69	83
Ethyl	15.25	66	Phylloxera	4.97	67	Photosynthesis	13.27	127
Antioxidant	13.63	120	Flow	4.81	136	Deficit	13.03	136
Concentration	13.02	568	Genotype	4.67	72	Mulch	11.97	105
Alcohol	13.00	170	Adaptation	4.55	250	Bud	11.79	172
Acetate	12.88	55	Vineyard	4.51	968	Veraison	11.59	129
Malolactic	12.74	54	Consumption	4.40	88	Defoliation	10.85	56
Aroma	11.06	119	Irrigation	4.23	340	Transpiration	9.72	74
Phenolic	9.57	171	Capacity	4.08	145	Shade	9.63	86
Winemaking	9.26	114	Need	3.94	191	Budbreak	9.37	51

Cluster 4: sustainability (total lemmas: 550)			*Cluster 5: modelling (total lemmas: 452)*		
Lemma	*Chi²*	*Total*	*Lemma*	*Chi²*	*Total*
Environmental	15.98	651	Model	21.63	1210
Ecosystem	13.45	137	Data	18.10	599
Carbon	13.28	337	Climatic	17.96	457
Habitat	12.50	106	Indices	15.45	158
Policy	11.68	113	Scenario	14.73	262
Conservation	11.55	141	Period	14.62	522
Economic	11.02	157	Precipitation	13.33	199
Ecological	10.34	112	Series	13.25	140
Management	9.86	527	Trend	13.10	238
Sustainable	9.40	111	Weather	12.73	222
Rural	9.27	48	Variability	12.56	326
Social	9.22	79	Event	12.37	196
Strategy	8.73	205	Daily	11.50	151
Sector	8.73	101	Annual	11.40	188
LCA	8.28	50	Frost	10.26	157
Impact	8.13	700	Meteorological	10.09	74
Community	7.85	101	Predict	9.89	211
Biodiversity	7.76	55	Rainfall	9.69	193
Farmer	7.53	47	Phenology	9.69	217
Agriculture	7.12	306	Estimate	9.58	208

The evaluation of adaptation strategies in the wine industry (Topic 2) includes a total of 310 papers corresponding to 18% of the manuscripts found in Topic 1 and to 2.2% compared to the analysis of “climate change impact – adaptation strategies” subject in agricultural sector. In Fig. 3 the distribution of the above papers among journals was reported. A relevant amount of works is concentrated in a few number of journals, however this emerging topic seems to spread in different reviews.

The stress index of MDS output (0.12) depicts a fair correlation between the input matrix and Sammon's map (according to classification of Wickelmaier, 2003; Fig. 4).

Fig. 4 shows the categorisations of lemmas as well as research interests in the examined literature. The right and left sections of the graphic (first/fourth and second/third quadrants) appear to refer to two main themes. The right section focuses on temperature increase and its consequences on plants and fruit. The left section highlights a major interest in water deficits and drought impacts. The upper section of the figure (first and second quadrants) is mainly focused on the effects of climatic conditions on vines and wine (see lemmas “cultivar”, “grape”, “berry”, “vine”, “plant”, “yield” and “crop”). The lower section, in general, concerns issues that may be helpful to overcome CC

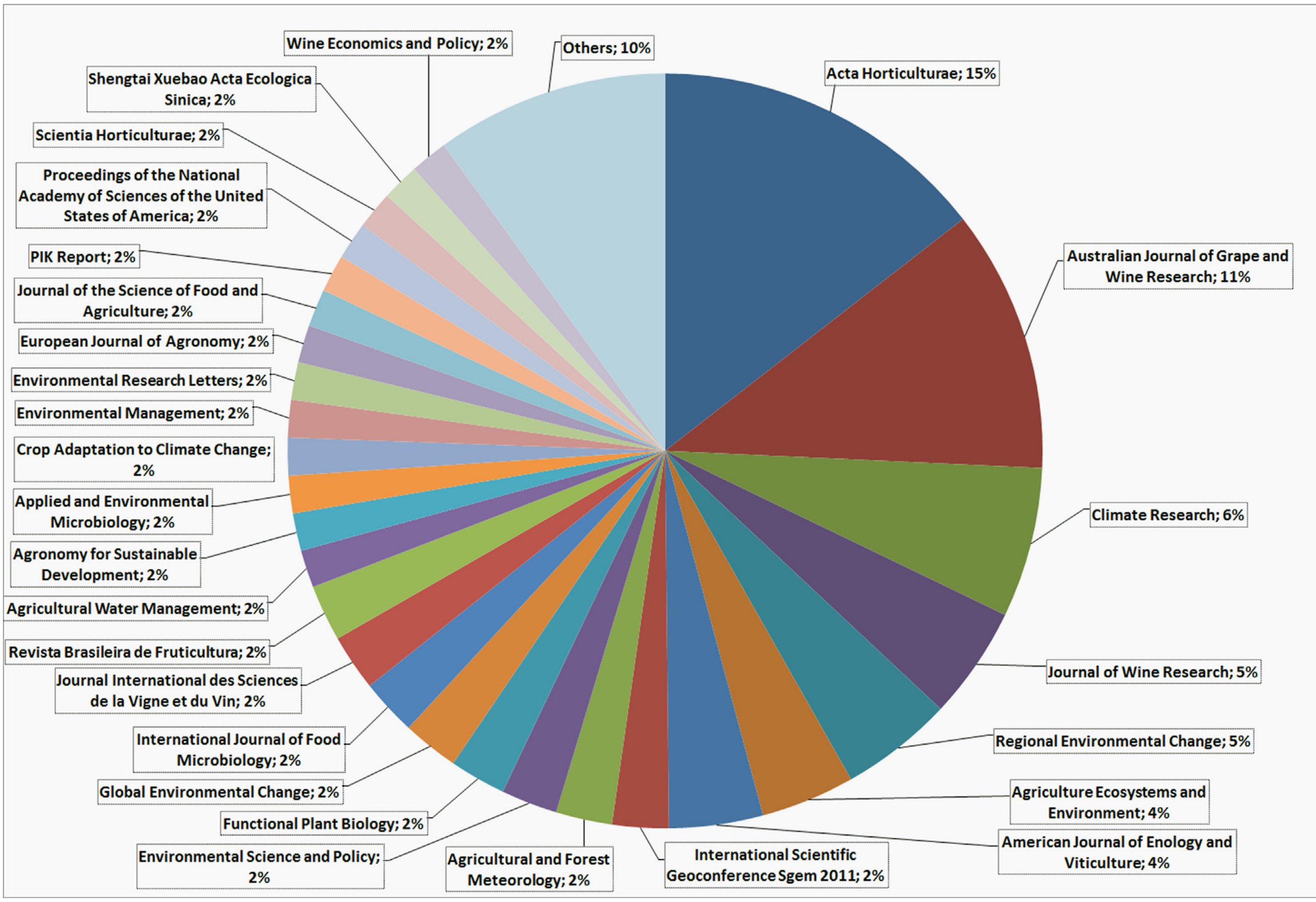

Fig. 3. Distribution of papers in scientific journals (Topic 2: Climate change - Adaptation).

impacts. Scenario analysis is a frequent topic in these research papers and is often developed at the regional level. Management techniques are also included, in particular those taking into account the efficiency of irrigation practices on water stress. Modelling impacts at the plant or regional level is often found in papers exploring water deficit, but other negative effects are also analysed. In some studies the introduction of risk analysis is shown. Another included subject is the use of specific vine varieties and cultivars. The quantification of lemmas' importance (circles size) shows how – with the exception of main terms such as "climate change" and "wine" – no significant prevalence of expressions is evident. Only a subtle predominance of temperature increasing is denoted in scientific literature related to adaptation strategies.

An in-depth evaluation of how adaptation strategies have been analysed at the country level is reported below (Topic 3). The ten main producers of wine at global scale published a total of 194 relevant manuscripts, which is equal to 63% of the total scientific papers analysed in Topic 2. All continents are represented in this sample (Fig. 5).

Australia is the nation with the highest number of papers published for this subject (52), followed by several countries located in northern hemisphere i.e., Spain (29), France (28), Italy (25), the United States (25) and Germany (15). A lower absolute value of publications is shown for the other nations. Fig. 5 reports the number of scientific works in Topic 3 normalised according to Eq. 1. It is of interest to note that Mediterranean countries have the highest score, followed by Chile and Australia. Intermediate values are shown by Germany, Argentina and the United Stated. China and South Africa have low weights within Topic 3.

Specificity analysis depicts the main research interests for the different nations within Topic 3 (Table 4).

In Table 4, the ten basic lemmas for each country are reported. The reduced number of papers published in Argentina show only eight significant terms for specificity analysis. They are related to the Intergovernmental Panel on Climate Change (IPCC) scenarios, the effect of greenhouse gases emission on plant physiology and the importance of mitigation as well as adaptation policies. Australian research highlights the effects of climatic parameter variation on maturation phases and potential stresses for vines. The adaptation analysis is well defined by lemmas that reveal both the assessment of field intervention ("leaf", "canopy", "rootstock") and innovation strategies ("innovation"). The impact of CC in the Chilean wine sector seems to be evaluated in terms of potential impact on the socio-economic pillars of sustainability. Market analysis as well as proper management of the local chain with a particular emphasis on human and social aspects are relevant themes

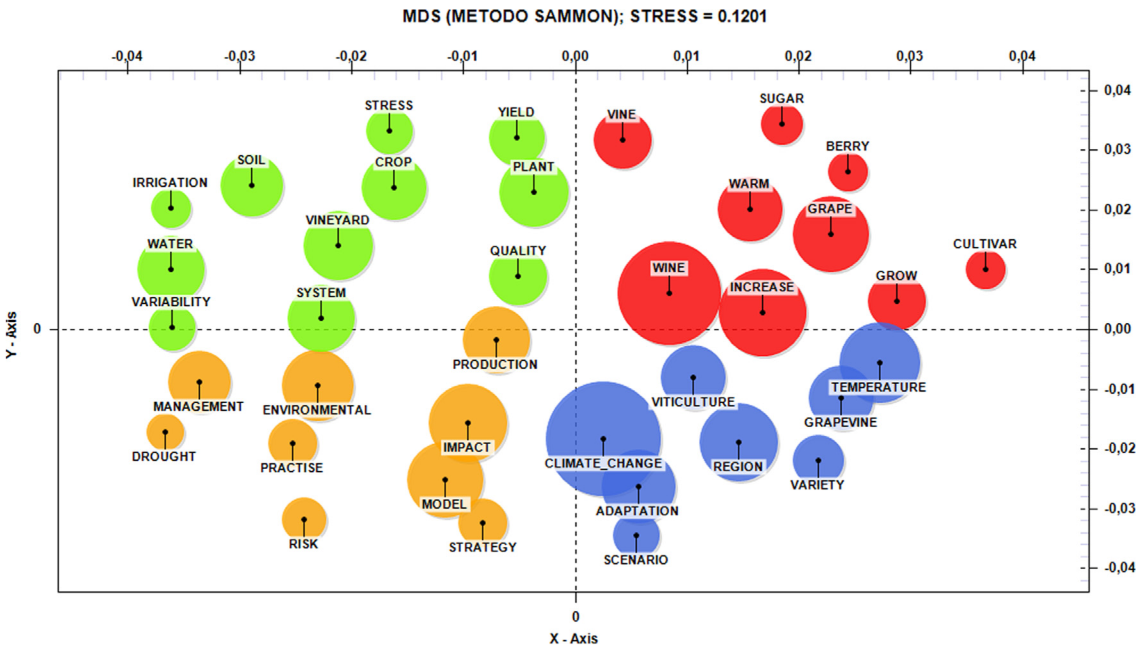

Fig. 4. Multidimensional scaling map for Topic 2 (Climate change - Adaptation).

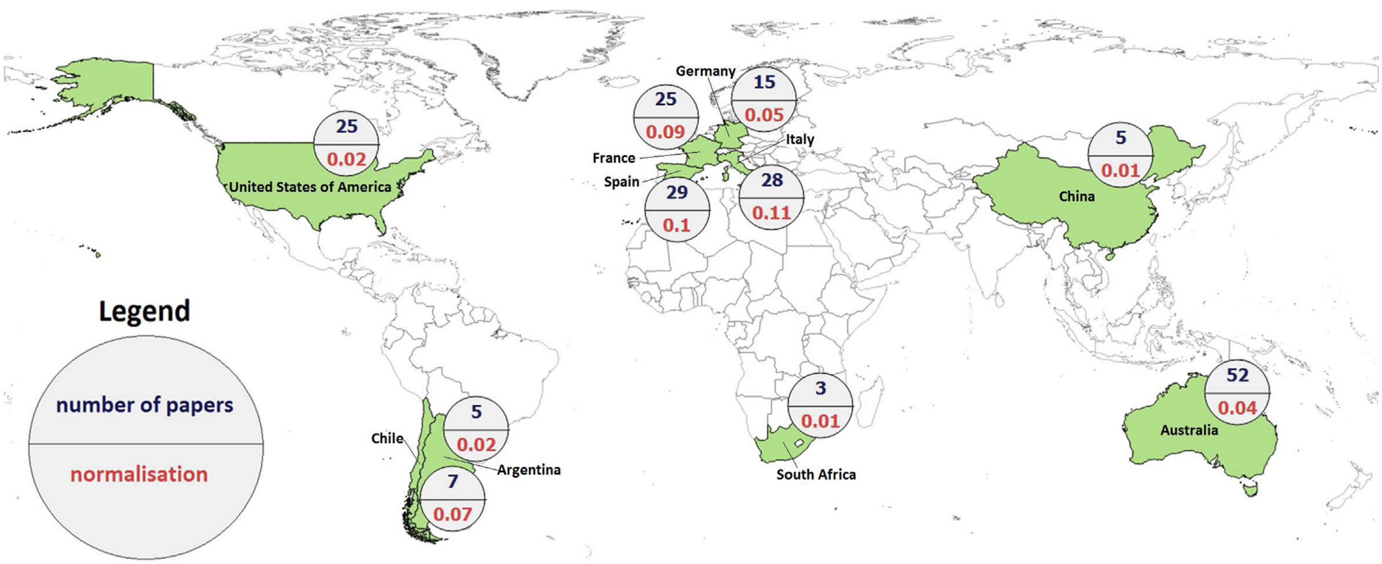

Fig. 5. Number of papers and normalised value at the country level (Topic 3: Climate change – Adaptation – *Nation*).

emerged here from quantitative literature review. Specificity of the few manuscripts published within China are concentrated on the selection of appropriate cultivars for specific zones, denoting the importance given to the choice of suitable variety, probably due to higher potential for new plantations with respect to other countries. The literature review for France highlights three main specific classes of interest: the principal group is related to infection risk due to fungi and pathogens and relative reaction of plants. The "Bordeaux" lemma introduces the *terroir* concept, denoting a strong relevance of local areas for production of high quality wines. Then, as confirmation of statements presented in the Introduction section, high significance is revealed for modelling of the wine sector as an integrated and complex system (see terms "model" and "system"). Winemaking interventions seem to be a nation-specific strategy analysed in German scientific works. Indeed, total acidity ("titratable_acidity"), fermentation phase ("saccharomyces_kudriavzevii", "saccharomyces_cerevisiae", "yeast") as well as additional vinification aspects ("sugar", "strain") are presented as central lemmas in this literature review. Similar to France, Italy reveals the strong importance of regional peculiarities for wine production ("Tuscany"). Publications are mainly concentrated on plant plasticity and adaptability for different problems such as soil erosion and pathogens ("downy_mildew"). The "precipitation" lemma can be here considered as an indicator of both water stress and extreme events analysis. South African papers are concentrated on how CC can impact specific geographic locations. The

Table 4
Specific lemmas for country related to Topic 3 (Climate change – Adaptation – *Nation*).

Argentina			*Australia*			*Chile*			*China*			*France*		
Lemma	*Total*	*Chi²*	*Lemma*	*Total*	*Chi²*	*Lemma*	*Total*	*Chi²*	*Lemma*	*Total*	*Chi²*	*Lemma*	*Total*	*Chi²*
IPCC	16	238.82	Veraison	27	34.86	Producer	20	125.68	Specie	56	253.86	Pesticide	12	60.01
Emission	69	109.93	Elevate	14	30.45	Economic	38	32.46	Grape	172	224.02	Infection	13	53.74
Physiology	13	38.21	Innovation	21	25.43	Human	13	18.75	Zone	16	72.40	Tolerance	10	25.99
Extreme	17	27.90	Response	56	17.09	Market	15	15.54	Cultivar	61	23.60	Disease	105	21.01
Variation	32	24.26	Concentration	22	14.73	Opportunity	15	15.54	Plant	116	21.31	Bordeaux	13	17.10
Resource	20	22.90	Leaf	44	11.54	Vulnerability	17	13.10	Estimate	27	21.04	Model	200	12.01
Policy	20	22.90	Canopy	11	11.50	Strategy	61	10.41	Ripen	40	12.51	System	97	11.14
Greenhouse	30	13.51	Sustainability	10	9.24	Project	63	9.80	Scenario	76	9.80	Fungal	10	10.74
			Rootstock	23	7.23	Manage	12	8.06	Select	10	6.13	Genome	18	9.23
			Stress	42	5.19	Social	16	5.22	Technology	11	5.41	Pathogen	18	9.23

Germany			*Italy*			*South Africa*			*Spain*			*United States*		
Lemma	*Total*	*Chi²*	*Lemma*	*Total*	*Chi²*	*Lemma*	*Total*	*Chi²*	*Lemma*	*Total*	*Chi²*	*Lemma*	*Total*	*Chi²*
Titratable_acidity	10	56.66	Tuscany	12	49.55	Weather	55	58.16	Red	13	40.81	Biochar	20	55.70
Sugar	45	43.70	Erosion	15	35.44	Spatial	32	53.05	Acohol	11	40.16	Cold	18	54.14
Beet	27	26.20	Plasticity	11	17.89	Industry	86	44.79	Experimental	14	27.95	Bud	12	39.56
Riesling	15	23.01	Soil	155	16.30	Scale	35	29.08	Dry	19	22.25	Control	34	33.57
Saccharomyces_kudriavzevii	21	20.37	Downy_mildew	18	14.81	Variability	52	17.29	Yield	126	20.16	Insect	14	31.52
Strain	21	20.37	Resistant	10	13.85	Thermal	17	15.06	Cabernet_sauvignon	14	14.21	Treatment	32	31.25
Risk	64	19.31	Exposure	31	11.25	Daily	20	12.27	Irrigation	44	13.61	Uncertainty	25	15.43
Hybrid	27	19.24	Adaptability	35	10.98	Location	20	12.27	Water	126	10.38	Heat	16	12.84
Saccharomyces_cerevisiae	15	14.55	Precipitation	39	10.81	Atmospheric	21	11.51	Rainfall	33	9.42	Perennial	13	12.15
Yeast	17	11.87	Simulation	32	10.38	Temperature	236	8.67	Organic	21	9.41	Survival	10	11.66

influence of climatic variability on wine quality and the wine industry is estimated by atmospheric modelling. The focus of Spanish publications highlights that one of the major threats to the Mediterranean wine sector is the risk of water stress and drought. The impacts on particular cultivars ("cabernet_sauvignon") and low-input adaptation strategies ("organic") have been tested in scientific papers. Research from the United States reveals the importance of evaluating uncertainty. Among specificities, a focus on extreme temperatures ("cold", "heat"), the potential impact on plants and grapes ("bud", "survival") as well as adaptation strategies and studies ("biochar", "control", "treatment") are depicted.

4. Discussion and conclusion

The analysis of climate change (CC) impacts on the wine sector is a very recent research topic. The majority of scientific works concerning Topic 1 were, in fact, developed within the last few years. They have focused on both general analyses related to sustainability and normative rules and specific themes (e.g., winemaking techniques, field operations or modelling the effect of climatic parameters variation on vine phenology). From a sustainability viewpoint, CC impact analysis for wine industries is mainly focused on environmental characteristics with respect to social and economic ones. Indeed, in the first phase of complex system analysis a simplification and focus on ecological aspects seems to be necessary, as confirmed in other sectors (see, e.g., Diaz-Chavez, 2006).

Topic 2 contained only 18% of the papers within Topic 1. This suggests that research activity has been mainly focused on the potential effects of CC on the wine industry, and only recently an interest has emerged for adaptation and defensive strategies. Adaptation issues were concentrated on the potential negative effects of climatic variation. In particular, scenarios and best strategies to overcome an increase of temperature and water deficits have been examined. Risk assessment has been introduced in the scientific literature; however, a lack of research papers focusing on uncertainty analysis seems apparent.

The evaluation of how adaptation strategies have been studied at national scales suggests that the highest number of manuscripts were published in Australia, Mediterranean countries, central Europe and the United States. The normalised number of papers stresses the importance given to adaptation strategies analyses in nation with both high qualitative wine standards and elevated risks of impact due to CC (in particular for water stress). The reduced scores of China and South Africa are probably due to high significance of agricultural subjects (e.g., for food production) and a relative recent history in wine production for both countries. The last hypothesis seems also to be confirmed by the specificity analysis for China that depicts a high importance of cultivar selection and zonation strategies. *Terroir* and quality issues appear conspicuously for France and Italy.

The main findings of the paper are useful for both research and practical purposes. The techniques presented permit researchers to define the principal themes analysed in scientific literature. The application of a statistical tool to textual data facilitated a quantitative literature analysis, ensuring replication of the results. The methods allow for evaluation and assessment of a high number of papers with respect to traditional qualitative and quantitative analyses. In this way, the subjectivity related to "hand-made" classification can be overcome. A multi-scale approach can be applied in literature reviews by evaluating manuscripts from the global to local level. From practical point of view graphical illustration also facilitates presentation and diffusion of results; as matter of fact policy-makers, wine producers and other local stakeholders can be informed about state-of-the-art of specific CC impacts as well as adaptation strategies to cope with negative effects of CC. The appraisal of works referring to specific temporal ranges promotes future updating of outputs.

Among the main limitations, are the lack of evaluation of internal consistency of the text, which must be considered in future research. For example, the positive/negative assessment of lemmas and specific relations among terms would be a relevant future tasks. In addition, there is a clear need for critical evaluation of both input and results. Other databases could be included in the analysis, while particular care must be taken for determining the suitability of sources (e.g., in case of blogs, social network, etc.). Additional misinterpretation of results can occur when in scientific texts there are words linked to other sectors but without relevance for the purpose of the article (e.g. comparative examples) or when a word is written once and then repeated with acronyms. However the application of title, abstract and keywords as in the present case allows to minimise the above risks.

Based on the results of this work, future studies should further explore different topics, in particular i) a comprehensive evaluation of adaptation strategies differentiated for specificity of local contexts; ii) integrated assessment of CC impact on wine industry to assess the wine sector as a complex and nonlinear system; iii) the importance of mixed-method techniques for topic modelling; iv) in-depth risk computation and the evaluation of uncertainty related to implemented scenarios; v) the application of text mining on additional digital media to understand the scientific, human and societal perspectives on the future in relation to CC for the achievement of a "virtual" participative approach and vi) analysis of information-dissemination processes to local stakeholders. Total or normalised number of papers can be applied to depict statistical relevance and correlation among produced manuscripts and additional variables (e.g., quality of wine, amount of production and consumption as well as turnover) to reveal potential short/medium term trends in research. One final remark regards the attention of the current scientific literature on 'active' forms of adaptation strategies. These seem to be mainly concentrated on process innovation focused on technological aspects as well as field and winemaking operations. Future work should also investigate appropriate policies for adaptation measures concerning the protection or recalibration of the denominations of origin. In this framework, the typicality of products due to terroir and local peculiarities could be reinterpreted using dynamic trends and terms related to CC effects. In other terms, a potential in-depth evaluation should also concern product innovation and not only process innovation.

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