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Review Article

Grapes, Wines, and Changing Times: A Bibliometric Analysis of Climate Change Influence

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Climatic conditions play a major role in wine production. Given the increasing impacts and risks posed by climate change, it is important to understand the effects it will have on the wine sector and different wine-producing regions worldwide. This study provides an in-depth examination of the scientific discourse on wine and climate change from 2000 to 2022 by conducting a bibliometric analysis of the literature published on the Web of Science database, which included 1,314 publications. The use of quantitative and qualitative methods allows us to investigate how research has evolved over the years. Our analysis uncovers the most productive countries, institutions, and journals leading the research in this domain, while emphasising the multifaceted approach to studying wine and climate change. Nevertheless, numerous research areas are yet to be adequately explored. Through co-citation analysis and bibliographic coupling, we identify dominant thematic clusters in previous and current scientific literature and reveal emerging research trajectories in this field. The main thematic clusters found include the assessment of climate change effects on viticultural regions worldwide, climate change's impact on grape composition, and the impact on grape phenology. Our results can be useful not only to understand the main themes studied until now but also to orientate researchers towards less explored aspects and disciplines in scientific research.

1. Introduction

Climate change (CC) has become one of the most debated and important topics among public and policy makers in the last decades. The latest assessment report produced by the *Intergovernmental Panel on Climate Change* (IPCC) illustrates the impacts and risks posed by CC and, once again, highlights the absolute need for governments and policy makers to limit the increase of global temperatures to 1.5°C above preindustrial levels in the next decades [1].

Climatic conditions play a major role in wine production, and the effects of CC on this sector are becoming increasingly apparent. Indeed, the *International Organisation of Vine and Wine* (OIV) estimated the average wine world production in 2022 at 259.9 million hectolitres, representing a 1% decrease compared to 2021 and the fourth consecutive year where global production is slightly below the average of the past 20 years [2]. In 2022, adverse weather events have been experienced across different regions. Hot temperatures and drought have caused important European producers like Spain and Portugal (third and fifth largest European producers) to experience significantly lower productions than the previous year (−6% and −8%, respectively). Drought and lack of water supply have caused a 4% decrease in production (compared to 2021) in the USA as well; in the Southern Hemisphere, production has registered a 7% decline (compared to 2021, which was a record year) due to unfavourable weather conditions, including heavy rainfalls and cold spring temperatures. France, on the contrary, has reported the highest growth rate in the European Union (+17%) compared to the previous year (2021, a very low vintage, characterised by severe damages due to early frost in April) [2]. Indeed, during the last decades, climatic conditions have been found to vary erratically from year to year [3], resulting in a high volatility in production volumes at regional levels, which makes forecasting even more difficult for producers [2]. On the other hand, a changing climate can also benefit countries that are not traditionally suited for wine production. This is particularly evident in Great Britain, where hectares under vine have more than doubled in the last eight years and more than quadrupled since 2000 [4], signalling how much the impact of CC is becoming increasingly tangible in wine production.

However, even though vine is cultivated in many different regions around the world, each with diverse and specific climates, the best wines are produced in temperate climates, since hot conditions may result in unbalanced wines which lack aromatic expressions [3]. Moreover, climate appears to impact vine development and fruit composition more than other factors, such as soil and grape variety. Indeed, in wine-producing regions, the variations of climatic conditions from one year to the other induce the so-called "vintage effect," which results in yearly variations in yield, quality, and typicity. Thus, in order to adapt to climatic variability among vintages, growers have to choose different plant materials and modify viticultural practices [5].

For these reasons, changing climatic conditions may potentially lead to significant implications, such as alterations in grape fruits' ripening timing and even the ability to grow grapevine in specific regions. Consequently, numerous studies have explored the diverse effects of CC on wine production. Jones et al. [6] investigated the impact of CC on wine quality, revealing that many European regions have already reached their "optimum growing season" temperatures. Therefore, with projected temperature increases over the next five decades, it will become very difficult, if not impossible, to maintain the current quality of fruits and wines [6]. Similar studies have also been published about other wine regions worldwide, including the USA [7, 8] and Mediterranean Europe [9–12]. Even future projections predict an increase in temperatures in many areas, with implications for current production levels and the quality of wines [13–15]. Dramatically, in a study conducted by Hannah et al. [16], the authors estimated that in major producing regions, there could be a decrease in suitable area for viticulture between 25% and 73% by 2050. However, the authors did not consider the role that the implementation of adaptive strategies by producers may have in maintaining quality levels, as shown by van Leeuwen et al. [17]. Moreover, new viticultural areas will be emerging worldwide [18–20].

Scientific literature illustrates different issues arising from future climatic changes. Indeed, there will be effects on the development of vines and the composition of grapes and wines. In particular, several studies show that in many viticultural areas, there has been, during the last decades, an advancement in the timing of phenological events [21–23]; these trends are also confirmed for future years [24–27]. CC is already having an impact also on grape composition, particularly concerning important anthocyanins, with consequences also on the quality of wines [28–30].

Given the wide literature addressing the topic and the relevance of these evidences, there is a relevant number of literature reviews about wine and, in particular, its relationship with CC. Among these, Mozell and Thach [31] have reviewed the scientific literature concerning the causes and effects of CC and the challenges that it may cause to wine production, while also providing some practical solutions to adapt wineries and vineyards. van Leeuwen and Darriet [5] have produced a detailed review of the effects that the changing of climate-related factors will have on vine development and fruit composition, with positive or negative implications on wine quality depending on the region and the amount of change [5]. Moreover, Sacchelli et al. [32] have published a quantitative literature review about the adaptation strategies in the wine sector to CC, considering publications from 1990 to 2015. The authors show that these research topics have been emerging in recent years but also that literature still lacks a thorough study of adaptation strategies [32]. Instead, a review of the economic implications was published by Ashenfelter and Storchmann [33]: CC will mostly affect European producers, but the authors also notice that many studies only consider average temperatures, while ignoring the effect of extreme ones. Moreover, in their opinion, many analyses do not consider the possibility of farmer adaptations, thereby strongly increasing the impact of CC on wine production [33]. Within this wide body of work, a pioneering work by Alonso Ugaglia and Peres [34] introduced the use of a bibliometric approach to synthesise decades of information on the topic. They used a citation network analysis to pinpoint the foundational elements and significant trajectories within this research field, using a dataset of 782 references spanning from 1991 to 2016. This groundwork was fundamental; however, our research takes a more advanced step by employing a wider array of bibliometric tools, including co-citation analysis and bibliographic coupling, on a substantially larger and updated dataset. Indeed, the data analysed include all publications dealing with CC and wine, across all possible subject categories including Economics, Business, and Management, which, in previous reviews, have not usually been considered. We consider this to be an important aspect, since the wine industry has reached a record global export value of 34.3 billion euros in 2021 [35]. Employing both co-citation analysis and bibliographic coupling, we try to assess what are the main thematic clusters of past and current scientific research, thus allowing to understand its development over the years. In doing so, this paper tries to fill a gap in the scientific literature on wine and CC [36].

The next section describes the methods used to develop our dataset and analyse the data. The following section presents the main findings, with a general description of the scientific literature included in our dataset, a focus on the Economics, Business, and Management research areas and an illustration of the co-citation and bibliographic coupling networks. Then, the main results are discussed. Finally, the article ends with the conclusions and limitations of our work, including implications for future research.

2. Methodology

2.1. Bibliometric Analysis. The methods used in this paper are part of the so-called "bibliometric analysis," which was developed in the 1950s and 1960s by Garfield [37] and Price [38]. According to this methodology, bibliometric data (e.g., number of publications or citations of an article) are analysed through a set of statistical methods to evaluate research on a specific topic. As stated by Wallin [39], "bibliometric methods are quantitative by nature, but are used to make pronouncements about qualitative features." Thanks also to the development of scientific databases such as Scopus and Web of Science, it is now possible to analyse very large quantities of bibliometric data [40]. The bibliometric analysis can be divided into *performance analysis* and *scientific mapping*. Performance analysis is used to evaluate the impact of different actors (that is, authors, institutions, journals, and countries) on the basis of bibliographic data [41], while science mapping is employed to create spatial representations of bibliometric networks to explore the interrelation between research areas, institutions, papers, and authors [42, 43]. Science maps can be obtained through different methods; in this paper, we will use co-citation analysis and bibliographic coupling, which are presented in the next paragraphs.

2.2. Co-Citation Analysis and Bibliographic Coupling. Co-citation analysis is one method of science mapping in bibliometric analyses, first proposed by Small [44] and Marshakova [45] as a method for document coupling. Small defines it as "the frequency with which two items of earlier literature are cited together by the later literature" [44], and it is used to map the structure of a research field by pairing documents that are frequently cited together [41]. This means that both publications are referenced by a third publication, and their link is stronger as the number of papers citing both of them increases. The fundamental assumption is that co-citation clusters reveal underlying intellectual structures; thereby, the study of a co-citation network focuses on interpreting the nature of a cluster of cited documents and the interrelationships between clusters [46]. However, given that the older a document, the longer the period in which it may have been cited, this method is considered biased towards "the past" of an academic field [47]. Nevertheless, the structure of linkages among publications for a specialty may be observed to change over time; thus, co-citation analysis provides a tool for monitoring the development of scientific fields [44].

Bibliographic coupling is another technique for science mapping, introduced in the 1960s by Kessler [48]. Different from co-citation, it is a method in which clusters are formed when two or more documents share one or more source documents [49]. This type of analysis assumes that publications with similar references will also share similar research contents. Contrarily to co-citation, bibliographic coupling allows the detection of current trends and future priorities since documents that include citations are more recent than the documents they cite. Indeed, here the focus of the analysis is shifted from *cited* to *citing* texts, using the latter to form the clusters and thereby emphasising younger publications and emerging trends in a specific field [47].

In this research, we aim to provide two different perspectives regarding scientific literature on wine and CC: firstly, through co-citation analysis, we can identify the publications (and the investigated themes) that can be considered the theoretical foundations of this research field, by creating and describing thematic clusters. On the other hand, bibliographic coupling allows us to show, through thematic clusters as well, what are the more recent research trends, shedding light on current issues and investigations. Results appear to be complementary, with similar thematic clusters emerging from the two analyses, but they also show an evolution towards different and innovative approaches and more in-depth analyses. For this reason, we decided to include both co-citation analysis and bibliographic coupling in our research.

2.3. Search Strategy and Data Representation. The bibliographical data used in this analysis were exported from Clarivate's Web of Science (WoS), one of the leading scientific research databases, which has long been considered the "gold standard" for bibliographic analyses [50]. In our search on WoS, we used data available from the Web of Science Core Collection, including all editions of their Citation Indexes. We also mostly based our query on the one used by Jamali et al. [51], but including terms related to CC as well. So, we considered the field Topic ("TS" in advanced search, which includes: Title, Abstract, Author Keywords, and Keywords Plus), and the topical queries used were as follows: (wine OR wines OR grapevine* OR "wine grap*" OR "wine pro*" OR winemaking OR enolog* OR oenolog* OR viticult* OR vitis) AND ("climat* chang*" OR "global warming" OR "climat* influenc*") (the asterisk (*) allows to include all wildcards of the terms considered (e.g., "climate" and "climatic")). We also restricted the results to only consider articles written in English.

The initial dataset consisted of 1,619 articles, spanning from 1992 to 2022. We then reviewed the record obtained one by one, reading the titles and abstracts, to ensure they were related to wine and CC. Moreover, since between 1992 and 1999 only two articles were present in the dataset (one in 1992 and one in 1996), we decided to consider the time period between 2000 and 2022, so as to give more continuity to the analysis of the dataset. Through these steps, we obtained a final dataset of 1,314 articles.

Data from Elsevier's database Scopus were also considered for this paper. Using the same search query applied to "Article title, Abstract, and Keywords" and considering again only articles written in English, we obtained 1,405 publications for the time period 2000–2022. After reviewing the records collected one by one, we obtained a final dataset consisting of 1,209 articles, that is, more than 100 articles less compared to our final WoS dataset. For this reason, it was decided to use data from WoS.

The data obtained from the WoS dataset were then processed through three kinds of software. Firstly, the R-tool *Bibliometrix* [52] was employed to perform the introductory part of performance analysis (that is, the quantitative analyses regarding scientific publications, authors, countries, institutions, and sources). Then, CiteSpace [53] was used to illustrate the frequency of keywords over time. Instead, VOSviewer [54] was employed to generate co-citation and bibliographic coupling maps and to cluster documents. In

Table 1: Quantitative analysis of research on wine and CC.

Year	Total publications	N of authors	N au/N docs	Times cited	Average number of citations	N of references	N refs/N docs
2000	1	2	2.0	483	483.0	42	42.0
2001	1	7	7.0	151	151.0	33	33.0
2002	1	2	2.0	43	43.0	21	21.0
2003	0	0	0.0	0	0.0	0	0.0
2004	2	4	2.0	137	68.5	94	47.0
2005	4	14	3.5	1264	316.0	99	24.8
2006	4	22	5.5	703	175.8	149	37.3
2007	5	23	4.6	690	138.0	244	48.8
2008	9	20	2.2	658	73.1	411	45.7
2009	9	45	5.0	666	74.0	375	41.7
2010	21	70	3.3	1912	91.0	954	45.4
2011	24	96	4.0	1344	56.0	989	41.2
2012	40	186	4.7	2165	54.1	2032	50.8
2013	48	226	4.7	2392	49.8	2670	55.6
2014	55	270	4.9	2418	44.0	3064	55.7
2015	64	346	5.4	2176	34.0	3639	56.9
2016	97	456	4.7	3390	34.9	5618	57.9
2017	96	542	5.6	2522	26.3	5329	55.5
2018	114	560	4.9	2271	19.9	6799	59.6
2019	118	613	5.2	1485	12.6	6494	55.0
2020	175	1008	5.8	2085	11.9	10472	59.8
2021	197	1034	5.2	1063	5.4	12234	62.1
2022	229	1362	5.9	506	2.2	15084	65.9

order to construct a map, VOSviewer calculates a similarity matrix based on a co-occurrence matrix; subsequently, the VOS mapping technique is applied to the similarity matrix [55]. The similarity measure used by the software is called *association strength*, and it allows to obtain distance-based maps in which the strength of the relationship between two items is reflected in the distance between the items (a smaller distance should equal to a stronger relationship) [56].

2.4. Data. From Table 1 and Figure 1, it is possible to get an overview of the trends in research on wine and CC during the entire period considered (2000–2022). We can notice that there has been a steady growth in the number of publications and authors since 2004. Also, we can notice that the only publication from 2000 has a higher number of citations than the ones from subsequent years (in fact, there is an overall decrease from 2005 onwards); this may imply that the article published in that year is probably still considered a pillar even in current research on wine and CC.

As shown in Figure 1, there has been an increase in the number of publications and authors regarding these subjects during the years considered, but there has also been a significant decrease in the average number of citations for publications (except for the year 2010). However, this is not completely unexpected, since more recent papers have been in the public domain for less time, so they have had fewer chances of being cited with respect to earlier publications.

3. Results

Tables 2 and 3 show the geographical distribution of the research on wine and CC. Firstly, Table 2 reveals that the most productive country in this type of research is Italy, which contributes to nearly 18% of the publications found in our dataset; following, there are Spain, Australia, France, and Portugal as the rest of the top five most productive countries. These results are not particularly surprising, given that these five countries are renowned producers of high-quality wines. It should also be noticed that, among the top 15 most productive countries, seven (that is, nearly half of them) are part of the so-called "New World wine" producers. Moreover, the presence of China among these countries can certainly be considered an interesting factor in the geography of the research, seemingly confirming the recent increasing trends among its population in the consumption and production of wine [57].

Even when considering the most productive affiliations among all authors, as shown in Table 3, Italian institutions seem to be the most remarkable contributors, with four universities ranking in the top 15 by number of publications between 2000 and 2022. However, the top three positions are occupied, respectively, by the University of Bordeaux (France), the University of Adelaide (Australia), and the University of Trás-os-Montes Alto Douro (Portugal).

Figure 2 illustrates the network of collaborations between the top 20 countries in wine and CC research between 2000 and 2022, based on the total strength of the co-authorship links with other countries. The countries with the highest *total link strength*, represented by the largest nodes in Figure 2, are Italy, France, USA, and Spain. In this case, the *total link strength* attribute (computed by VOSviewer) indicates the total strength of the co-authorship links of a given country with other countries. This means that countries with a higher total link strength tend to have a more solid and wider network of collaborations with other

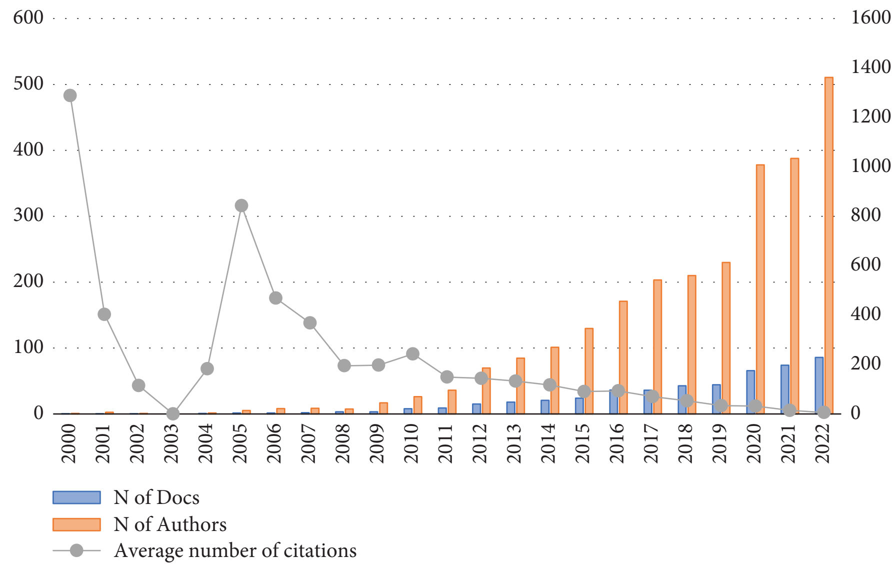

FIGURE 1: Trends of wine and CC publications, authors, and citations.

TABLE 2: Top 15 most productive countries in wine and CC research.

Countries	*N*	SCP	MCP	%
Italy	234	167	67	17.8
Spain	212	157	55	16.1
Australia	120	84	36	9.1
France	112	67	45	8.5
Portugal	97	62	35	7.4
USA	95	64	31	7.2
Germany	43	32	11	3.3
China	39	30	9	3.0
Romania	30	27	3	2.3
Argentina	24	14	10	1.8
Greece	24	14	10	1.8
Canada	19	15	4	1.4
Turkey	19	18	1	1.4
Chile	17	11	6	1.3
Brazil	16	12	4	1.2

Note. SCP = single country publication; MCP = multiple country publications.

TABLE 3: Top 15 most productive institutes in wine and CC research.

Institutes	*N*
Univ Bordeaux (FRA)	68
Univ Adelaide (AUS)	62
Univ Trás-os-Montes Alto Douro (PRT)	48
Univ California Davis (USA)	47
Univ Navarra (ESP)	40
Univ Florence (ITA)	37
Univ Cattolica Sacro Cuore (ITA)	36
Univ Montpellier (FRA)	35
Univ Perugia (ITA)	35
Hochschule Geisenheim Univ (DEU)	33
Univ La Rioja (ESP)	33
Univ Melbourne (AUS)	30
Univ Lisbon (PRT)	29
Univ Padua (ITA)	26
Michigan State Univ (USA)	25

countries, thus occupying a more central position in the geographical distribution of the research. It is also interesting to notice that the network's illustration seems to indicate a greater number of academic collaborations among, on the one hand, researchers from the "New World" countries (such as Australia, USA, and Canada) and, on the other hand, between authors from the "Old World" countries (such as Spain, Italy, and Portugal).

Table 4 illustrates the top 15 journals that published articles regarding wine and CC, including the number of their total publications between 2000 and 2022 (it is worth mentioning that some of these journals were first published after 2000, such as *OENO One* and *Agronomy-Basel*). Publications can be found in journals covering many fields, such as viticulture, agronomy, meteorology and climate, plant biology, sustainability, and environmental research. However, the number of publications also seems to be highly fragmented among the different sources, with 1,314 articles from 330 journals (that is, an average of around four publications per source). The *Australian Journal of Grape and Wine Research* published the highest number of articles in the dataset, while *OENO One* is the journal where articles about wine and CC have the highest percentage with respect to the total articles published by the same journals (16.58%).

Concerning the most common research areas associated with publications on wine and CC, as shown in Table 5, they are more commonly related to agriculture, food, and environmental sciences and meteorology, with the three categories occupying the top three positions being "Food & Science Technology" (13.6%), followed by "Plant Sciences" (12.3%), and "Environmental Sciences" (11.6%). This ranking shows that the relationship between wine and CC is a multidisciplinary research topic, covered by many scientific areas. However, it remains largely unexplored from the point of view of many of

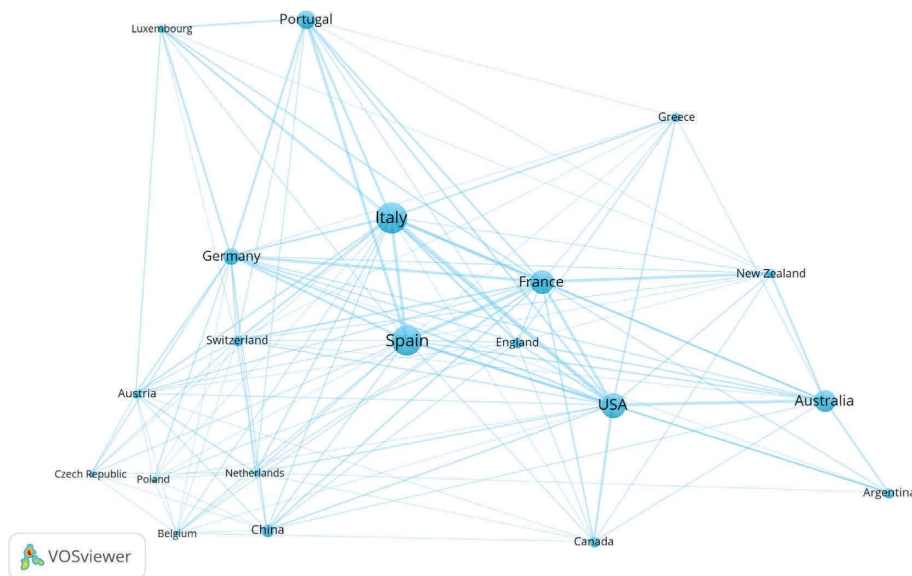

Figure 2: Network of collaborations between countries.

Table 4: Ranking of the 15 most productive journals.

Sources	*N*	TP (2000–2022)	%
Australian Journal of Grape and Wine Research	75	903	8.31
Agronomy-Basel	73	9,225	0.79
OENO One	66	398	16.58
Frontiers in Plant Science	48	22,061	0.22
Plants-Basel	39	9,057	0.43
Agricultural Water Management	32	6,087	0.53
Agricultural and Forest Meteorology	26	4,929	0.53
American Journal of Enology and Viticulture	23	2,176	1.06
Sustainability	23	59,621	0.04
Journal of Cleaner Production	22	32,806	0.07
Vitis	22	860	2.56
Science of the Total Environment	21	52,086	0.04
Climate Research	20	1,500	1.33
International Journal of Biometeorology	20	2,575	0.78
Scientia Horticulturae	18	9,848	0.18

Note. TP = total publications between 2000 and 2022.

these research areas, such as, for example, economics and engineering, which have a low number of pertaining publications. This confirms that the research on these subjects is relatively new and investigated mainly by traditional research areas such as agriculture and food and environmental sciences.

3.1. Publications in the Economics, Business, and Management Subject Categories. The focus will now be on the publications in the database included within the WoS categories of "Economics," "Agricultural Economics & Policy," "Business," and "Management," for which the total number amounts to 42 articles between 2008 and 2022. Although the first articles in this cluster are from 2008, we only have a continuous presence of at least 1 article from 2014 onwards. This proves that the analysis of the economic relationship between wine and CC has only recently gained attention and remains a largely unexplored topic, as evidenced by the limited number of publications dedicated to this area of study.

The total number of countries with at least one publication in one of the categories here considered is 17, with Table 6 illustrating the ranking of the most productive ones. The USA and Australia are the leading countries in this research area, with 13 and 12 publications, respectively, followed by Italy (10) and France (6). From this ranking, it can be noted that there is still an even division between "New World" wine-producing countries (Australia, USA, and Canada) and "Old World" producing countries (Italy, France, and Germany). Table 7, instead, shows the ranking of journals by the number of publications. These are mostly journals concerning business, economics, and development research, apart from the first one, "Journal of Wine Economics," which is specifically about economic topics relative to the wine sector.

Table 5: Ranking of the most common research areas.

Research areas	*N*	%
Food Science & Technology	312	13.6
Plant Sciences	282	12.3
Environmental Sciences	265	11.6
Horticulture	204	8.9
Agronomy	194	8.5
Meteorology & Atmospheric Sciences	138	6.0
Agriculture, Multidisciplinary	80	3.5
Environmental Studies	65	2.8
Green & Sustainable Science & Technology	54	2.4
Water Resources	47	2.1
Biotechnology & Applied Microbiology	46	2.0
Environmental Engineering	38	1.7
Ecology	35	1.5
Chemistry, Applied	34	1.5
Forestry	34	1.5

Note. Publications can be associated to more than one research area, so the percentage is computed based on their total observations (2,290) and not on the number of publications (1,314).

Table 6: Ranking of most productive countries with more than one publication.

Countries	*N*	SCP	MCP
USA	13	8	5
Australia	12	6	6
Italy	10	5	5
France	6	3	3
UK	3	1	2
Canada	2	0	2
Germany	2	2	0

Note. SCP = single country publication; MCP = multiple country publications.

Table 7: Ranking of journals with more than one publication.

Sources	*N*
Journal of Wine Economics	13
Journal of Business Ethics	3
British Food Journal	2
Ecological Economics	2
Regional Studies	2

Table 8 reports the top 10 publications in this research area by the number of total citations. The papers share some common elements in this ranking that can be highlighted. Firstly, the most cited paper [5] is a thorough review of the effects and impacts that changing temperatures, water status, and radiations have on vine development, fruit composition, and wine quality. This is obviously important knowledge for anyone willing to investigate this topic from an economic perspective, since yield and quality are the main factors for the wine industry. Similarly, Schultz [58] and Ollat et al. [3] reviewed as well the main challenges posed by climate change to wine production (which generally involve either warmer and drier or warmer and wetter environmental conditions, depending on the region), while also stating that further multidisciplinary research is needed not only to assess its economic impact on specific regions but also to develop adaptive and more sustainable production strategies. For example, in the future, we should expand the knowledge on greenhouse gas emissions and limit the carbon and water footprints of the wine sector; however, potential adaptations will mostly be different for each wine region [3, 58].

Ashenfelter [59], instead, aimed to predict (through a hedonic model) the variability in the quality and price of Bordeaux mature wines by using weather data from when the grapes are picked. Even though the focus of this work is not on climate change per se, the author suggests that it still provides a useful basis for assessing the effects of climate change on the wine industry [59]. In addition, the same author has subsequently authored an additional paper (still based on a hedonic model) that takes into consideration the expected impact of climate change on vineyards' quality and prices, with respect to the Mosel Valley region (Germany) [60]. The results show that a 1°C temperature increase would increase land value in the region of 20% or more, while a 3°C increase would more than double the land value [60].

Moreover, wineries are by nature related to so-called "ecosystem services" (ESs), which can be defined as the benefits that people obtain from ecosystems, including food and water, but also spiritual and cultural benefits [61]. For this reason, Galbreath [62] analysed how an Australian multinational wine firm responds to climate change, also considering ES constraints. He found three categories of actions undertaken by the firm: *governance area*, *mitigative actions*, and *adaptive actions*.

Another important issue regarding climate change effects is whether and how specific regions and industries will adapt to them. Galbreath [63] considered wine firms in the Margaret River region, Western Australia, to analyse their response actions to climate change. The results show both mitigative and adaptive actions at different levels and rates of implementation; location theory and economic barriers appear to be critical drivers of trade-offs between the types of response action. Still looking at Australia, in particular the Upper Hunter region, McManus [64] argues that, despite being an economically sustainable region (due to its diverse economic base: mining, thoroughbred breeding, and vineyards), it is not environmentally sustainable; thus, a strong sustainability shift is required in order to promote regional sustainable development.

3.2. Frequency of Keywords over Time. Relative to research areas, the analysis of the evolution of the keywords used in the research on wine and CC can provide a good overview of how the focus and topics of interest in the literature have shifted during a specific period. Indeed, Figure 3 illustrates how keywords in the publications regarding wine and CC have changed over the years, allowing us to understand how the objectives and the focus of research have changed as well over time. The illustration was obtained through the software CiteSpace.

Table 8: Top 10 most cited publications in the economics, business, and management research areas.

Year	Authors	Article title	Total citations
2016	van Leeuwen, C; Darriet, P	The impact of climate change on viticulture and wine quality	280
2008	Ashenfelter, O	Predicting the quality and prices of Bordeaux wine	104
2010	Ashenfelter, O; Storchmann, K	Using hedonic models of solar radiation and weather to assess the economic effect of climate change: The case of Mosel Valley vineyards	65
2016	Schultz, HR	Global climate change, sustainability, and some challenges for grape and wine production	63
2011	Galbreath, J	To what extent is business responding to climate change? Evidence from a global wine producer	51
2016	Ollat, N; Touzard, JM; van Leeuwen, C	Climate change impacts and adaptations: New challenges for the wine industry	40
2014	Galbreath, J	Climate change response: Evidence from the Margaret River wine region of Australia	39
2008	McManus, P	Mines, wines and thoroughbreds: Towards regional sustainability in the Upper Hunter, Australia	32
2011	Duarte Alonso, A; O'Neill, MA	Climate change from the perspective of Spanish wine growers: A three-region study	25
2016	Galbreath, J; Charles, D; Oczkowski, E	The drivers of climate change innovations: Evidence from the Australian wine industry	25

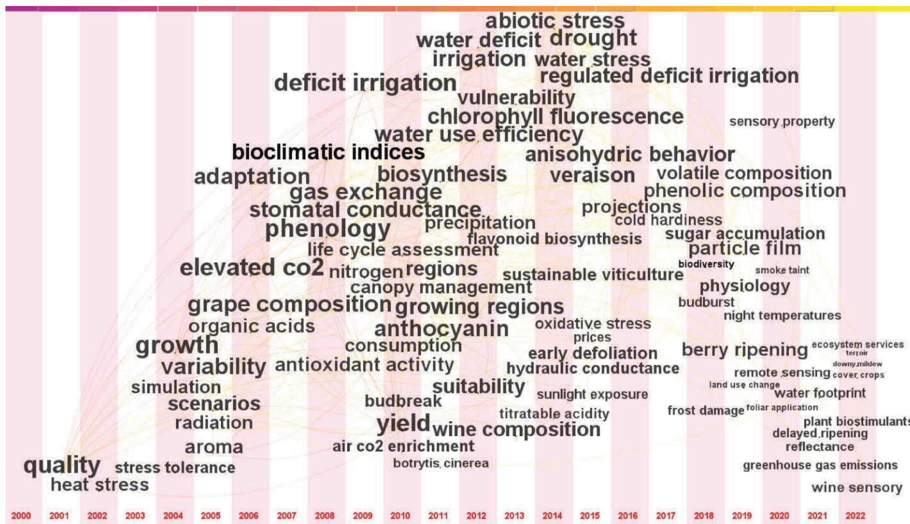

Figure 3: Time zone view of keywords in articles from 2000 to 2022. The size of the words is proportional to their frequency.

Initial years, characterised by fewer publications and thus a lower number of keywords, nonetheless set the stage for recurring themes that will be investigated thoroughly during the following years. *Quality* and correlated keywords such as *aroma*, *grape composition*, and *organic acids* indicate an early interest in the potential impact that new climate *scenarios*, including *elevated* CO_2, may have particularly on grapes' characteristics. Terms such as *heat stress*, *simulation*, *variability*, and *adaption* also indicate that researchers were already asking themselves how grapevines will be able to cope with respect to these emerging effects of CC.

Research on these main general topics has then become more and more specific during following years. One of the main themes that has been developing from 2008 to the present day regards the development of plants and the correlated agricultural practices (*phenology*, *canopy management*, *budbreak*, *early defoliation*, *veraison*); this focus may suggest a growing emphasis on using practical methods to minimise and mitigate the effects of CC on grapevines.

Starting at around 2009, keywords such as *stomatal conductance* and *deficit irrigation* clearly mark the beginning of a focus on the relationship between grapevines and water. This is a topic that has been (and continues to be) further explored, even more in-depth, in more recent years, as shown by terms like *water deficit*, *drought*, *regulated deficit irrigation*, and *water footprint*, which signal an increasing concern regarding water availability and its efficient use in warmer climates. In 2009, we can also notice how terms related to wine and grape composition start becoming more specific, possibly indicating a shift in the focus of the research on the impact that CC may have on wine and grapes' specific components (*antioxidant activity*, *anthocyanin*, *titratable acidity*, and *wine composition*). In particular, from 2018, there seems to be an increased scientific production with respect to compounds linked to wine's taste and aroma (*volatile composition* and *phenolic composition*); these are also connected to successive keywords, in the final years of Figure 3, related to the perception of wine's properties (*sensory property* and *wine sensory*), showing a coherent evolution of these topics.

Additionally, in later years, we can also notice an increasing interest in the impact that CC may have not only on viticulture per se but also on viticultural areas considered as more complex environments (*biodiversity*, *land use change*, and *terroir*). Moreover, keywords such as *remote sensing* and *plant biostimulants* may indicate a growing attention towards innovative agricultural practices that may help viticulture become more sustainable and efficient, through the use of innovative technologies and new materials.

3.3. Co-Citation Analysis. As previously discussed, co-citation analysis connects publications when they appear together in the reference list of another publication, revealing not only the most influential publications but also the intellectual structure of a research field and its thematic clusters [40]. Here, the results of the co-citation analysis will be illustrated.

Table 9 illustrates the ranking of the top 15 most cited publications inside the database obtained from WoS. Even though a higher number of total citations do not automatically mean higher quality, it certainly gives an idea of the influence that publications may have had on the research in a specific area. From the table, it can be noted that Jones et al. [6] is by far the most cited publication (371 citations by documents inside our database), followed by Jones and Davis [22]; Hannah et al. [16]; Mira de Orduña [28]; and Duchêne and Schneider [21]. As already mentioned, Jones's research (2005) highlights the role of climate change in wine quality variations, and how its impact will not be uniform across regions and varieties; Hannah's work also focuses on the impact of CC on wine-producing regions [16]. Similarly, Jones and Davis [22] and Mira de Orduña [28] both illustrate the influence of climate on grape phenology and composition, such as sugar concentrations and alcohol levels, and wine quality.

Table 9: Ranking of the 15 most cited publications.

Year	Authors	Article title	IC	TC
2005	Jones, GV; White, MA; Cooper, OR; Storchmann, K	Climate change and global wine quality	371	753
2000	Jones, GV; Davis, RE	Climate influences on grapevine phenology, grape composition, and wine production and quality for Bordeaux, France	203	483
2013	Hannah, L; Roehrdanz, PR; Ikegami, M; Shepard, AV; Shaw, MR; Tabor, G; Zhi, L; Marquet, PA; Hijmans, RJ	Climate change, wine, and conservation	201	447
2010	Mira de Orduña, R	Climate change associated effects on grape and wine quality and production	189	500
2005	Duchêne, E; Schneider, C	Grapevine and climatic changes: A glance at the situation in Alsace	183	318
2007	Webb, LB; Whetton, PH; Barlow, EWR	Modelled impact of future climate change on the phenology of winegrapes in Australia	148	279
2004	Tonietto, J; Carbonneau, A	A multicriteria climatic classification system for grape-growing regions worldwide	141	446
2016	van Leeuwen, C; Darriet, P	The impact of climate change on viticulture and wine quality	139	269
2007	Mori, K; Goto-Yamamoto, N; Kitayama, M; Hashizume, K	Loss of anthocyanins in red-wine grape under high temperature	123	611
2000	Schultz, HR	Climate change and viticulture: A European perspective on climatology, carbon dioxide and UV-B effects	115	573
2010	Duchêne, E; Huard, F; Dumas, V; Schneider, C; Merdinoglu, D	The challenge of adapting grapevine varieties to climate change	111	190
2010	Chaves, MM; Zarrouk, O; Francisco, R; Costa, JM; Santos, T; Regalado, AP; Rodrigues, ML; Lopes, CM	Grapevine under deficit irrigation: Hints from physiological and molecular data	106	542
2010	Keller, M	Managing grapevines to optimise fruit development in a challenging environment: A climate change primer for viticulturists	106	229
2002	Spayd, SE; Tarara, JM; Mee, DL; Ferguson, JC	Separation of sunlight and temperature effects on the composition of *Vitis vinifera* cv. Merlot berries	105	772
2012	Sadras, VO; Moran, MA	Elevated temperature decouples anthocyanins and sugars in berries of Shiraz and Cabernet Franc	103	216

Note. IC = number of citations by documents of the dataset; TC = total number of citations.

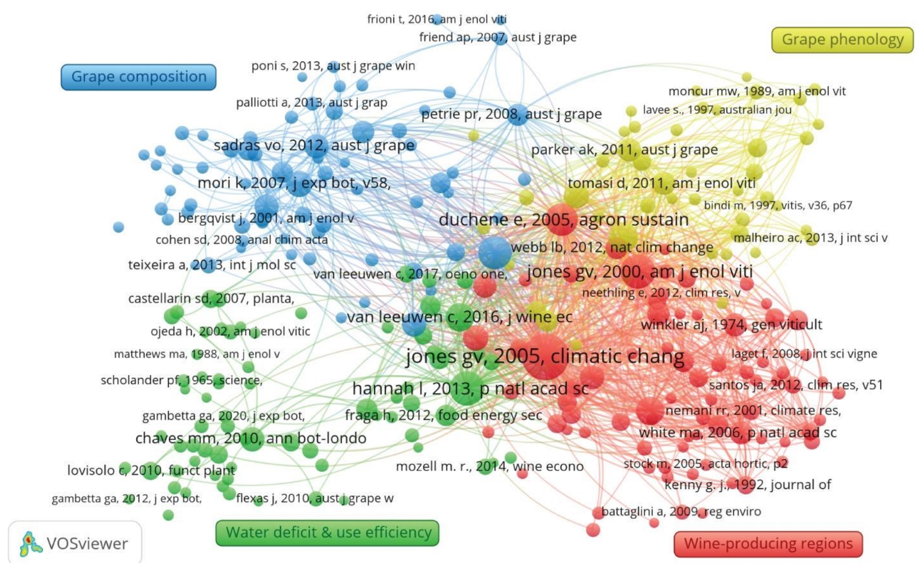

Figure 4: Co-citation network.

The software VOSviewer allows a graphic illustration of the co-citation analysis network, shown in Figure 4. In the network, the items represented are the documents that have been cited together. Larger labels and circles denote articles that have been cited a higher number of times. Lines between the items represent links, meaning they have been cited together. Moreover, the closer two items are located to each other, the stronger their relatedness and the higher their likeliness of being cited together. In order to focus on the key publications and to better understand and interpret the network, the minimum number of citations of a cited reference was set at 20, thus resulting in 263 valid references, which are the ones illustrated in the network. From this co-citation analysis, four clusters reflecting investigated topics in the research on wine and CC have been highlighted. These include 77 papers in cluster 1, 72 in cluster 2, 69 in cluster 3, and 45 in cluster 4, respectively.

3.3.1. Cluster 1 (Red): Effects on Wine-Producing Regions. The first cluster appears to be largely composed of papers that aim to highlight how the change of different climatic factors can affect wine-producing regions and the quality of their wines, possibly changing the future geography of wine production. In general, many studies in this cluster illustrate how increasing temperatures will have a detrimental impact and cause difficulties in producing wines (especially high-quality ones), since many of the world's wine regions are already at or near their optimum growing season temperatures [6]. In particular, Jones and Davis [22] have used data from Bordeaux, France, to investigate the relationships between climate and phenology, berry composition at harvest, production, and quality. They observed an advance of phenological stages, a shortening of phenological intervals, but also a tendency to a higher sugar to acid ratios and an increase in potential wine quality. Similarly, a subsequent study regarding Alsace, another wine region in France, shows that, during the last decades, the period between budburst and harvest has become both earlier and shorter, with ripening occurring under increasingly warm conditions [21].

Among the expected consequences of CC, increases in heat accumulation and the frequency of extremely hot days could cause a significant reduction in the potential premium winegrape production area in the United States [8]. Specifically for coastal California, asymmetric warming and increases in sea surface temperatures and water vapor may increase the risk of future pest/disease outbreaks [7]. Moreover, bioclimatic indices based on daily temperatures and precipitation data have also allowed to predict warming and increased dryness, with detrimental impacts especially over Southern Europe and Mediterranean Europe [10–12, 65, 66]. Rising solar radiation levels will also directly impact grape and wine quality in European viticultural regions [67].

Given the threats CC poses to wine regions and production, some researchers included in this cluster used climatic indices to classify and analyse the suitability of wine regions. For example, Tonietto and Carbonneau [68] have considered three viticultural climatic indices: dryness, heliothermal, and cool night (night temperatures). These were then used for the classification and zoning of grape-growing regions worldwide and to help study sites for new viticultural areas [68]. Instead, Hall and Jones [69] have calculated consistent climate indices and integrated them with their spatial characteristics, showing that, within Australian wine regions, the spatial variability of those indices can be significant. Also, this introduced a helpful measure to understand cultivar suitability within wine regions, while also enabling the comparison of different viticultural regions [69].

3.3.2. Cluster 2 (Green): Water Deficit Effects on Grapevines and Water Use Efficiency. This cluster primarily includes articles that examine the consequences of water shortages and droughts on viticulture, along with methodologies to enhance water use efficiency (WUE) and the interplay between water deficits and climate studies.

The impacts of climate change are not evenly distributed worldwide. Greater warming trends have been observed in the Northern Hemisphere [31], potentially fostering a significant realignment in production towards regions with higher latitudes and elevations [16]. In the context of future climate change scenarios, water scarcity is often presented as a stark reality confronting global populations. Such scarcity will pose significant challenges for wine production, given the integral role water plays in grape cultivation and quality assurance.

Water deficits can, first, lead to a reduction in berry size, thereby causing an increase in the skin-to-pulp weight ratio and, subsequently, in the quantity and concentration of skin tannin and anthocyanin per berry [70–72]. Drought responses among different grapevine cultivars are often tied to isohydric or anisohydric stomatal behaviour, which can be regulated by the cultivar's hydraulic conductance [73, 74].

Given the predicted developments in climate and the importance of water availability in winegrowing, there will certainly be a need to improve resource management. Research will have to expand their focus both at plant level (physiological mechanisms and genetic background) and vineyard level (such as soil) to develop new resilient and sustainable practices [75], such as increasing soil water storage capacity, using cultivars with a higher WUE or reducing early transpiration losses [76].

3.3.3. Cluster 3 (Blue): Effects on Grape Composition. The documents that are part of the third cluster mostly illustrate the impacts that CC-related events and factors (such as increasing temperature, dryness, and solar radiations) can have on the composition of wine grapes and, consequently, on the quality of the wine. Indeed, annual variations in climate, and especially temperature, typically outweigh changes caused by cultural practices [77]. Extremely hot temperatures may not only inhibit vine metabolism (thus affecting wine aroma and colour), but they may also result in increased grape sugar concentrations, leading to higher wine alcohol levels and to an increased risk of spoilage and organoleptic degradation of the wine [28].

Several of the publications in this cluster also focus on the impact that higher temperatures can have on the concentration of anthocyanins in grape skins. The optimum berry temperature for anthocyanins is estimated at around 30°C; above 35°C, they stop accumulating [30] or may even be degraded [29]. Moreover, warming trends may also disrupt the "anthocyanin : sugar" ratio in berries, with consequences for the "colour : alcohol" balance in red wines [78]. Some studies in this cluster have also tried to separate the effects of light and temperature, by artificially cooling sun-exposed grapes and artificially heating shaded grapes; results show temperatures to be more responsible than light in the accumulation of anthocyanins [30, 79].

Light and temperature can also influence other flavonoids in grapes other than anthocyanins, such as flavonols (UV protectants and anthocyanin copigments) and tannins (responsible for wine's bitterness and astringency). Exposure to light of leaves and fruits increases flavonol accumulation; tannin accumulations are less well understood, but shaded fruit also has a lower tannin content throughout berry development [80].

An increase in atmospheric CO_2 levels is also considered in this cluster. Bindi's research shows that it may actually stimulate grapevine production without causing negative repercussions on the quality of grapes and wine [81]. These results were also partly confirmed by Salazar-Parra's work, but only in the case of a simulated climate scenario where elevated CO_2, elevated temperature, and partial irrigation interact [82].

3.3.4. Cluster 4 (Yellow): Effects on Grape Phenology. Documents in the fourth cluster mainly focus on the effects of CC-related events on the development of grapevines, which can be described by their phenological events. Since grapevines need to grow in a suitable climate in order to produce high-quality fruits, it is important to understand the main phenological stages of the plant (such as budbreak, flowering, and veraison), in order to better manage its growth cycle and production.

Indeed, phenology is considered to be a key factor to explain the distribution and diversity of current cultivars, and for this reason, the best strategies to adapt to future conditions can vary according to each different scenario considered [83].

In some European wine regions as well, there have been reports of a correlation between higher temperatures and earlier trends of significant phenological stages, such as bloom, veraison, and harvest dates [23]; warmer seasons also result in greater ripening potential, possibly altering wine quality due to an increase in sugar content [84].

Other publications in this cluster have, instead, used past climatic and phenological data in order to also make projections about future climatic and phenological trends. Overall, the predicted effect for climate change is a shortening of the growth season in grapes, with maturation occurring during hotter periods of the year [27, 85]. Caffarra and Eccel [86], in particular, have evaluated the potential effects of CC on grape phenology in different sites in Trentino, a mountain region in Italy, where viticulture is not currently present due to climatic limitations. The authors found that, before the end of this century, some mountain sites at about 1000 m are expected to become climatically suitable for viticulture, due to a trend of phenological advance [86]. In addition, phenological models have also been developed to predict specific stages of development (flowering and veraison) for many different varieties of grapevine [87–89].

3.4. Bibliographic Coupling. As already mentioned, bibliographic coupling divides publications into thematic clusters based on shared references [40], since documents are linked if they cite the same publications. This gives a more forward-looking perspective, eventually highlighting present and emerging trends in the research.

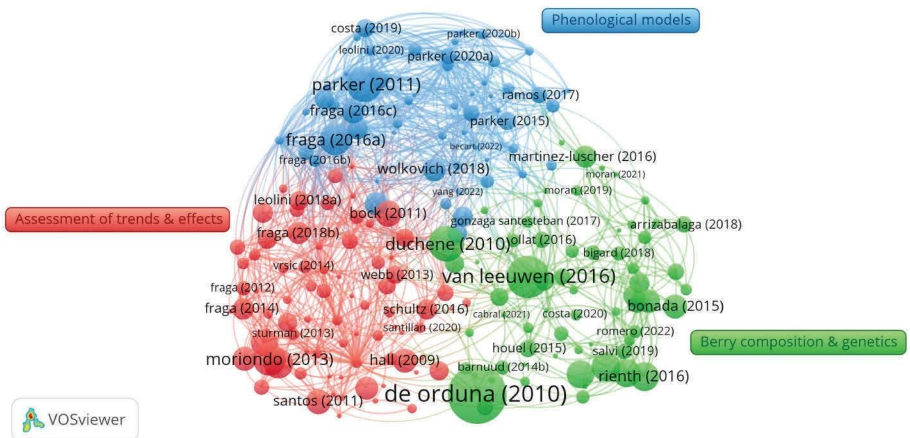

Figure 5: Bibliographic coupling.

Figure 5 illustrates the bibliographic coupling network, specifically the 200 documents from the initial dataset with the highest link strengths. As it can be noted, most of the publications shown in the network date from after 2010, confirming what was mentioned before about the focus on recent articles and trends from this analysis. In this case, three main research clusters have been formed, with themes somehow similar to those of the co-citation analysis. The three publications with the highest *total link strength* are Cabré et al. [18]; Fraga et al. [90]; and Fraga et al. [90].

3.4.1. Cluster 1 (Red): Assessment of (Future) CC Trends and Effects. In the first cluster, research is mainly focused on the assessment of present and, mostly, future climate projections and their impact in specific viticultural regions. Indeed, as already mentioned in this paper, wine production is highly affected by climate and weather, with a strong vulnerability to CC.

Some of the publications in this cluster show that, during the last decades, average temperatures (and night temperatures as well) have been increasing in most of the different regions considered, with possible implications for viticultural practices and grape varieties used [91], although, in certain areas, yield seems to not have been impacted strongly [92].

Many are the articles dealing, instead, with future projections of climatic conditions in different wine regions. The data suggest significant changes for several viticultural areas in future scenarios of temperature increase, with implications for thermal suitability, lower bioclimatic diversity, and a possible lack of water to maintain current production levels [13, 15]. Quality of wines could also be affected, and cultural practices may require variations [14]. Moreover, present and future climatic scenarios seem to indicate a possible expansion into new suitable vineyard areas around the world, including Argentina [18], England and Wales [20], and Poland [19].

The climate trends and projections aforementioned require researchers to also focus on adaptive strategies and solutions for wine producers. However, given the unique contexts to which different wine regions belong (from several perspectives, including environmental, economic, and social), it is important to understand how these factors will interact with different regional climates. Winegrowers will have to be assisted by researchers with more detailed and certain climate projections and analyses of local vulnerability, so as to provide them with optimal strategies at different temporal (short and long term) and spatial scales [93]. Indeed, CC will result in both winners and losers among wine regions, with European countries closer to the equator likely to be way more affected than others. This is also because European producers strongly emphasise location in their marketing; thus, strict appellation rules may have to be adapted to support these regions in overcoming future challenges [94].

3.4.2. Cluster 2 (Green): Berry Composition and Genetics. The main common theme among the publications that compose the green-coloured cluster is the analysis of the impact of CC with respect to the composition of grapes, which has a fundamental role in determining the quality of the final wine produced. Studies show that berries growing in warmer temperatures may have a decline in the levels of titratable acidity and anthocyanins, while pH levels will likely rise, with the rates of change in the berries being apparently cultivar dependent [95]. Bernardo et al. [96] also indicate that berry composition and grape phenology can be triggered by environmental stresses (including light, temperature, and water relations).

Given these challenges, this cluster illustrates some possible solutions, including research on genetic variability and control in order to breed new resistant varieties to a changing climate [97, 98]. In particular, the cultivar Tempranillo appears to have been employed by different researchers. It has been confirmed that increasing temperatures will lead to an advance in maturity of its grapes, with a decrease of total acidity and chances of a higher alcohol content [99]. Five clones of this particular cultivar have also been used to analyse the intravarietal variability in the response to CC-related factors, with different responses in the grape composition of Tempranillo clones to projected future temperatures and CO_2 levels [100].

3.4.3. Cluster 3 (Blue): Phenological Models in Viticulture. The third cluster in the bibliographic coupling is mostly about modelling of phenological stages; this confirms how a careful assessment and planning is becoming more and more important in this field, due to the increasingly tangible effects of CC on grapes and wine. Some of the papers in this cluster focus on the review of different phenology models, which can be used to simulate grapevine development under present conditions and future scenarios [101]. In particular, dynamic crop models not only simulate plant growth, but they are also able to integrate soil profiles, climate data, and management practices in their simulations; thus, they appear to be extremely helpful for both real-time monitoring and for long-term climate change projections [102].

Regarding the application of these phenological models, multiple papers in this cluster took into consideration three fundamental phenological stages in grape development: budbreak, flowering, and veraison (that is, when grape berries start changing their colour). Results from the application to future scenarios show an advancement in phenophase onset and shorter interphases [25, 90]. In addition, modelling of thermal conditions during these three phenological stages can also allow to understand spatial variability in specific areas, so as to provide maps to improve the adaptation of plant materials and training systems [103].

Another application, instead, considers modelling to predict the time to target sugar concentrations for *Vitis vinifera* L., so as to contrast the advancement in grapevine phenology and sugar accumulation in grape berries, providing a tool to avoid berries with excessively high sugar concentrations and, as a consequence, higher alcohol wines [104].

4. Discussion

This research reveals that the literature on wine and CC is quite recent, with 2000 being the first year in the WoS dataset after which there has been a continuous growth in the number of publications and in the number of authors as well. This indicates an increasing interest among researchers in the effects of CC on viticulture and wine.

Research on these topics appears to be multidisciplinary, with different subject categories covered by the publications in the dataset. However, most of the documents included belong to a few more "traditional" research areas, such as agriculture, food, and environmental sciences, while other categories still seem to remain underexplored. In particular, despite the economic importance of wine production worldwide (global export valued at €34.3 billion [35]), few studies in the dataset belong to subject categories related to Economics, Business, and Management. For this reason, it is important to highlight publications pertaining to these subjects. Interestingly, different themes emerge when considering the most cited publications in this cluster. Among these are hedonic models used to predict the impact of climate change on vineyards' quality and prices and the income of wine growers; the relationship between wine production and "ecosystem services"; and the adaptation strategies to climate change in specific wine regions (such as employing new heat-resistant varieties, improving water use efficiency, or introducing new agricultural practices).

In addition, this study has pointed out how the main contributing countries belong to the so-called "Old World" wine producers, such as Italy, Spain, and France, even if there is also a noticeable presence of producers from "New World" countries, such as Australia and the USA. It can be inferred that most of the research comes from European authors and countries because the European Union is also the largest wine-producing region in the world, with Italy, France, and Spain being the top three producing countries overall [2]. Nevertheless, when considering, instead, publications on wine and climate change belonging to the Economics, Business, and Management research areas, the USA and Australia are the countries with the most contributions, possibly implying a more business-oriented interest and approach with respect to their European counterparts.

However, this work aims to provide more than a general analysis of the main actors involved (that is, authors, countries, etc.) and citation count, by also applying the instruments provided by the bibliometric analysis, in order to visualise and describe the main themes investigated and the methodologies used by authors.

This study identifies similar thematic clusters in both the co-citation network and the bibliographic coupling analysis, thus allowing us to identify a seemingly common approach during past and more recent research, in the years considered. Indeed, it appears that research on wine and climate change is mostly divided into three main "layers." Firstly, there are assessments and predictions of climatic changes in viticultural areas worldwide; then, authors focus on the effect these changes will have on both grape phenology and grape composition, with a focus on water deficit and the effect of droughts. In this way, research seemingly shifts the focus from the "bigger picture" (that is, wine regions worldwide) to more specific studies about the consequences of CC on the development and composition of grapevines, including specific cultivars. This result appears to be in line with the findings from the evolution over time of the keywords used in the publications; indeed, from that analysis, it emerged as well that, over the years, themes have become more and more specific, moving from generic keywords such as *quality*, *yield*, and *growth* to more precise terms pertaining to phenology, grape composition, and climate-related conditions.

In particular, from the co-citation analysis, it appears that research in the early years focused on predicting the main impacts that CC will have on viticulture and wine, not only quality-wise, but also indicating possible shifts in the geography of production at a global level, with Southern Europe and Mediterranean Europe appearing to be among the producing areas more at risk. Then, given the predictions of warmer temperatures and a reduction in water availability, many subsequent studies illustrate the impact that these factors will have on grape phenology and the composition of berries. Higher temperatures will advance the maturity of grapefruits while also increasing the sugars in berries (leading to higher alcohol levels in wines) and altering the balance between anthocyanins (responsible for colour), aromas, and sugars. However, higher levels of carbon dioxide (CO_2) do not seem to impact the quality of grapes and wine.

As already mentioned, the same thematic clusters and approaches can be identified in the bibliographic coupling. Nevertheless, although research areas appear to have mostly remained the same, some differences can be pointed out. Firstly, from the more recent publications included in the bibliographic coupling, it appears to emerge the need, when assessing CC impact on viticultural areas, for certain and detailed climate projections in order to provide producers with adaptive responses more optimal to their specific context. This indicates the realisation by researchers that strategies will have to be heterogeneous to work effectively. Furthermore, while earlier scientific literature on the assessment of CC effects mostly favours the use of traditional climatic indices, more recent research (as suggested by the bibliographic coupling analysis) seems to focus on the review and employment of modelling, which seems to allow a better understanding of how plants will be affected and will behave under different future climatic conditions. In addition, when considering the impact of CC on grape composition, previous research mostly focuses on the study and evaluation of climatic factors' effects on grapes, while studies contained in the bibliographic coupling appear to shift the focus on innovative solutions, such as the identification and breeding of new varietals or cultivar clones that can better behave under new conditions.

Given that, as already mentioned, the research on wine and CC seems to be quite recent (our dataset covers the last 23 years, which is not a very long period of time overall), it is then unsurprising that the main research areas have remained mostly the same. Due to the rising number of publications and authors in this field, along with the growing importance of CC in public discourse, it is likely that research on wine and CC will continue to expand in future years.

5. Conclusions and Limitations

This bibliometric analysis has tried to highlight the main characteristics regarding the evolution of the research about wine and climate change between 2000 and 2022. As already mentioned, we have decided to conduct this type of analysis due to the chance that it offers to investigate large number of data while also allowing to highlight relevant qualitative features of the dataset.

Firstly, it can be noticed how, from 2000 to 2022, the number of publications and authors has largely increased. Moreover, geographically speaking, the research on wine and climate change seems to be equally divided among so-called "Old World" and "New World" wine-producing countries, with Italy, Spain, and Australia being the 3 most productive countries by number of publications on these subjects. With respect to the research areas covered by the publications on wine and CC, these seem to be mostly related to food technology and agriculture, with few covering other scientific areas such as economics or engineering, thus showing new opportunities for future research. In particular, research in the areas of Economics, Business, and Management related to wine and CC appear to be a more recent development. The number of publications in these areas has been consistently increasing only since 2014, and there has not been a steady trend in either the number of authors or publications over the years considered. However, inside this small cluster, research appears to be still multidisciplinary, with many different themes and approaches included, such as hedonic models, ecosystem services, and specific regional case studies.

Subsequently, we have employed co-citation analysis and bibliographic coupling as methods of scientific mapping, to better illustrate how publications can both influence and be influenced by one another. The clusters found in the two analyses seem very similar, and it may be due to the fact that, as already discussed, the scientific literature on wine and CC is very recent, with the period considered in this paper covering only 23 years (2000–2022). Nevertheless, the clusters in bibliographic coupling mirror the ones in co-citation by introducing new perspectives in both methodological and conceptual terms. In fact, they highlight the increasing importance of phenological modelling, genetics, and future climatic trends.

The interest in CC has increased in recent years, so more comprehensive explanations of the interactions between climate and vine are needed. In this regard, further studies must be carried out at different levels (region, plant, berries, etc.). Moreover, multidisciplinary and multiscale approaches should be implemented to better understand the factors involved in the plant-environment interaction. Finally, a wide space still exists for the research in economics and business, where the effects of CC on the wine market should be studied from both producers' and consumers' perspectives.

Bibliometric analysis has many advantages since it allows to investigate large quantities of bibliographic data, but it also has some downsides. Firstly, it does not allow to go in-depth regarding each of the publications considered, thus only allowing to give a superficial account of the main findings of specific articles. Secondly, since many authors tend to reference their own previous publications, this may cause a bias in the representation of highly cited works, especially (as in our case, at least for the first years considered), if there are not many authors and publications in certain research areas. Moreover, regarding this work in particular, the WoS database, despite including a vast majority of scientific articles, does not comprise all of them, so it only allows for an almost complete analysis. However, despite these limitations, this work still gives a chance to get an updated overall view of the geographic distribution and magnitude of the research on wine and climate change, allowing not only to understand what are the main challenges and themes studied until now but also to give a hint on what other less explored aspects the scientific research could focus on.

Data Availability

Data used for this work were exported from Clarivate's Web of Science database. They can also be requested by contacting the corresponding author.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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