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Mitigating Environmental Hotspots in the Italian Wine value Chain: Insights from a Narrative Review and Case Study Analysis

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Abstract

Over the last twenty years, attention towards climate change and sustainability has grown significantly, also influencing supply chains and the products or services they provide. This growing awareness has led to the need to analyze and better understand environmental impacts along supply chains to develop more sustainable practices. The agri-food industry is responsible for about 30% of global energy consumption and significantly contributes to greenhouse gas emissions released into the atmosphere. In this context, this thesis focuses on the characterization of environmental hotspots along the Italian wine value chain.

To understand what the critical points are. From an environmental point of view, along this value chain, various studies and case studies dealing with the topic were analysed. The thesis is therefore proposed as a review of the literature, with the aim of explicitly determining what the environmental hotspots are in the Italian wine value chain. Focusing on two main indicators: carbon and water footprint. From the literature examined, two main hotspots have emerged for this value chain: the production of glass bottles used for wine packaging and the vineyard phase. To provide the most complete overview possible, all the studies selected and analyzed applied a life cycle assessment methodology, to have a defined cradle to grave approach.

After the literature review phase, interviews were conducted with stakeholder of the sector, with the aim of understanding which solutions can be used to mitigate the impact of the hotspots highlighted by the literature. In addition to the alternatives, the interviews also aimed at understanding the possible positive and negative impacts of this solutions. This approach provides easy repeatability, enabling future comparisons to assess the effectiveness of sustainability interventions over time. These findings can serve as a foundation for future research and practical applications aimed at reducing the environmental impact of the wine sector.

Key-words: Wine value chain, Carbon footprint, Water footprint, Life cycle assessment.

Sommario

Negli ultimi vent'anni, l'attenzione verso il cambiamento climatico e la sostenibilità è cresciuta significativamente, influenzando anche le catene di approvvigionamento e i prodotti o servizi che forniscono. Questa crescente consapevolezza ha portato alla necessità di analizzare e comprendere meglio gli impatti ambientali lungo le catene di approvvigionamento per sviluppare pratiche più sostenibili. L'industria agroalimentare è responsabile di circa il 30% del consumo energetico globale e contribuisce in modo significativo alle emissioni di gas serra rilasciate nell'atmosfera. In questo contesto, questa tesi si concentra sulla caratterizzazione dei punti critici ambientali lungo la catena di approvvigionamento del vino italiano.

Per comprendere quali siano i punti critici, dal punto di vista ambientale, lungo questa catena di approvvigionamento, sono stati analizzati vari studi e casi di studio sull'argomento. La tesi si propone quindi come una revisione della letteratura, con l'obiettivo di determinare esplicitamente quali siano i punti critici ambientali nella catena di approvvigionamento del vino italiano, concentrandosi su due indicatori principali: carbon e water footprint. Dalla letteratura esaminata, sono emersi due principali punti critici per questa catena di approvvigionamento: la produzione di bottiglie di vetro usate per l'imballaggio del vino e la fase di vigneto. Per fornire la panoramica più completa possibile, tutti gli studi selezionati e analizzati hanno applicato una metodologia di valutazione del ciclo di vita, per avere un approccio definito dalla culla alla tomba.

Dopo la fase di revisione della letteratura, sono state condotte interviste con stakeholder del settore, con l'obiettivo di comprendere quali soluzioni possano essere adottate per mitigare l'impatto dei punti critici evidenziati dalla letteratura. Oltre alle alternative, le interviste miravano anche a comprendere i possibili impatti positivi e negativi di queste soluzioni. Questo approccio facilita la ripetibilità, consentendo confronti futuri per valutare l'efficacia degli interventi di sostenibilità nel tempo. Questi risultati possono servire da base per future ricerche e applicazioni pratiche volte a ridurre l'impatto ambientale del settore vinicolo.

Parole chiave: Value chain del vino, Impronta di Carbonio, Impronta idrica, Valutazione del ciclo vita.

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1 Introduction

In the last two decades the importance of climate change has grown exponentially, becoming one of the main global challenges. Governments, scientists and civil society recognize that the impacts of climate change threaten not only the environment, but also the economy, public health and food security, requiring immediate and coordinated action at a global level.

One of the most impacting sectors is the agri-food one [1].

According to the European Commission, the food sector *“covers all operators in the food supply chain (farmers, food industry, food retail and wholesale, and food service) and their suppliers of inputs and services (seeds, pesticides, fertilizers, machinery, packaging, repair, transport, finance, advice and logistics) [2].*

The agri-food industry accounts for approximately 30% of global energy consumption and is also a major contributor to greenhouse gas emissions (GHG) [3].

The wine sector is one of the most analyzed inside the agri-food system not only for its economic and social relevance, but also in relation to its environmental impacts [4].

Italy is among the largest wine producers in the world with 49 million of hectoliters produced in 2022, followed by France with 47 hl, Spain with 46 hl, USA with 26 hl and Australia with 11 hl [5]. Viticulture is also part of the country's historical and gastronomic identity. For this reasons, the focus of this work is on the Italian wine value chain.

Wine sector is of fundamental importance for Italy for a series of economic, cultural, social and environmental reasons.

The sector employs approximately 1.3 million people in agriculture, processing and distribution, generating a value of wine production at base prices of 4.6 billion euros [6].

Wine production in Italy is much fragmented: there are approximately 310 thousand wineries and the average surface area of a winery in Italy is only 2.5 hectares [7].

The importance of this research is given by two main reasons:

- One of the primary challenges for the global agricultural sector is addressing climate change and other environmental issues while maintaining production quality and sustainability [8].
- Consumers are increasingly interested in environmental sustainability, which significantly influences their choices when it comes to agri-food products [9].

The objective of the current thesis is to determine the environmental hotspots of the Italian wine value chain and to evaluate possible solutions to mitigate them.

Therefore, the research has the aim of answering two questions:

1. What are the environmental hotspots of the Italian wine value chain?
2. What are the alternatives to mitigate these hotspots?

For the first question, an analysis of scientific literature has been carried out. The narrative literature review was focused on analyzing studies that conducted Life Cycle Assessments (LCA) on the Italian wine sector, collected thanks to the search engine Google Scholar. The literature review is neither a bibliometric analysis nor a systematic review, but it is a narrative review aiming at analyzing the topic through the examination of scientific papers dealing with the subject.

For the second research question a case study analysis was conducted through interviews with wine producers and other actors involved in the value chain. The goal of the interviews was to understand what techniques can be used to mitigate the hotspots highlighted by literature.

Regarding the structure of the thesis, after the present introduction, Section 2 deals with the background by describing the Italian wine value chain, its main phases and its inputs and outputs. Section 2 also explains the key concepts in relation to environmental sustainability (e.g., hotspot, LCA, GHG emissions, etc.) and the functional units (FU) used in the analyzed papers.

Section 3 describes the methodology followed to carry out the research, explaining also the reasons behind the decisions regarding the literature search process and the structure of the interviews.

In Section 4 the results of the literature review in relation to Carbon Footprint (CF) and Water Footprint (WF) are analyzed, with the aim of clearly defining the hotspots of the wine value chain. Following the CF and WF assessments, results from the interviews are also shown and explained, highlighting what techniques are used to mitigate the hotspots in the value chain, with their main limitations and drivers.

Section 5 is dedicated to conclusion and further developments and summarizes the results of the thesis, recalling the limits of the work carried out and adding possible future implications or suggestions for future research.

2 Background

2.1. Italian wine value chain

To define the borders of this research, it is necessary to understand what the Italian wine value chain is and what it looks like.

Defining what a value chain is complex for several reasons, linked to its dynamic, multidimensional and often customized nature. The difficulty behind its definition comes from various reasons, e.g. multiplicity of involved actors, variety of sectors, dynamics and continuous changes, global interconnections, logistics and strategic aspects.

To define what a value chain is, it is useful to identify what a supply chain is first.

The meaning of supply chain has been defined by different economist but one of the most used definitions is: the supply chain is *“the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to the ultimate consumer. In other words, a supply chain consists of multiple companies, both upstream (i.e., value) and downstream (i.e., distribution), and the ultimate consumer”* [10].

Value chains focus upstream on integrating supplier and producer processes, improving efficiency and reducing waste, while value chains focus downstream, on creating value in the eyes of the customer [11].

In this work, the focus is on the activities that generate value for the customer; those phases are shown in *Figure 1*.

The wine value chain is a complex interweaving that starts from the cultivation of the grapes and reaches consumers' glass. It involves multiple actors: farmers, producers, oenologists, distributors and retailers. Each phase is essential to preserve product quality and create value. The process begins with vines' cultivation vines, followed by harvest, winemaking, bottling and storage. The finished product (a packed bottle of wine) passes through distribution channels and then it reaches the final consumer hands.

To better understand the overall framework of the Italian wine value chain and to identify the most critical steps, from an environmental perspective, it is necessary first to define the main phases that characterize this chain. In the following sections the steps of the wine value chain are illustrated, with particular attention to the inputs and

outputs for each phase. In *Figure 1*, the phases of the wine value chain considered and analyzed in the thesis are shown; their inputs and outputs are respectively on their left side and right side.

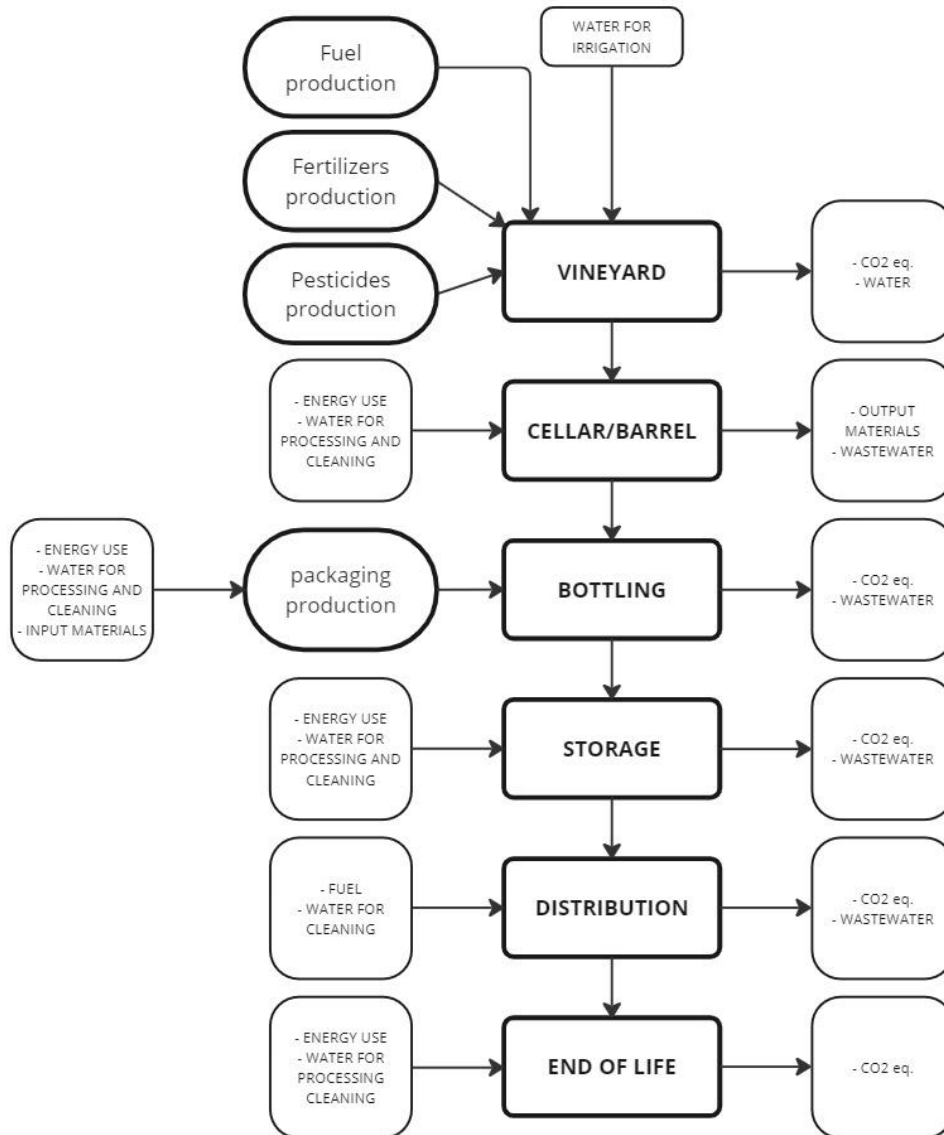


Figure 1- Italian wine value chain configuration (author's elaboration).

2.1.1. Grape-growing and maintenance

Starting off with the production system phases, the grape-growing phase refers to the activities carried out on fields and vineyards where grapes are grown and then collected. Vines are a distinctive feature of agriculture in all Italian regions, as they spread across almost every area, including mountainous regions and various altitude zones. This characteristic makes Italian viticulture unique compared to other traditional wine-producing countries, and especially to newer wine-producing regions, where vine cultivation is often limited to smaller and more specific areas [12].

According to AGEA (Agenzia per le erogazioni in agricoltura) the total surface used in Italy for grape-growing purposes in 2023 is approximately 675 thousands of hectares and the average surface for each company is only 2.8 hectares, showing a significant fragmentation of the first part of the chain [13].

After a vine plant is either planted or grafted, some common phases are present. From the “birth” of the plant, the first three years are not productive since the plant does not produce flowers (this number can vary based on various factors such as the type of grape, weather conditions and environmental aspects). After the third year the plant can develop flowers (during the late spring season), and those flowers become fruits by the second half of June. The fruits are referred to as grapes and are usually collected from the end of August until September or October depending on the maturity of the plant and other oenological parameters.

For this analysis, the plantation phase is not considered since a wine grape remains productive for decades, so the focus is on the inputs needed to cultivate and manage vineyards that are already productive.

Nowadays, viticulture is shifting toward a more sustainable approach, improving environmental and economic performances of these practices. For example precision viticulture is becoming more and more popular among grape-growing managers [8]. However, for this work, the focus will be on conventional activities that are still widely used in the Italian context, especially in small and medium-sized vineyards.

Usually when referring to the on-field stage of agricultural products, the main inputs to consider are:

- Diesel to fuel agricultural machinery which are usually powered by combustion engines.
- Organic and chemical pesticides and fertilizers
- Water use for irrigation purposes [14].

The impacts related to the materials to build and maintain the vineyard (poles, irrigation system, nets, etc.) are not considered.

2.1.2. Harvest and pressing

When the grapes are ripe in terms of acid and sugar content, they are harvested and pressed. In case of small vineyards and local businesses, the harvest can be done manually, with scissors and shears. In larger contexts, harvesting is carried out mechanically, thanks to machinery that shakes and collects the grapes.

The pressing process is done to extract the must and eventually filter the grape from branches and other debris.

This phase, in addition to wine, which will then be fermented, produces some by-products (which can be used in other sectors) such as alcohol, must and extracts [15].

With this step, the vineyard phase ends.

2.1.3. First fermentation

In this phase of wine processing, the must is transferred into tanks, which can be made of steel, wood or concrete. In these tanks the sugars present in the must are transformed into alcohol and carbon dioxide thanks to the action of yeasts [16]. This phase can also be called alcoholic fermentation. Depending mainly on the type of wine being produced, the winemaking process can change a lot. To produce white wine, the must is filtered and separated by the grape before the fermentation while to produce red wine, both the must and the grapes are fermented together [17].

This research focuses on the case of small-sized Italian wineries, therefore, this phase, as well as the other phases up to the distribution of the bottled wine, take place close to the vineyard itself, at most a few dozen kilometers away.

In the first fermentation phase, the control of parameters such as temperature and humidity of the rooms where tanks are placed is of crucial importance.

2.1.4. Maturing

The maturation of wine generically indicates a set of reactions which, over time, improve the taste and aroma of wine. The term "*maturation*" refers to the changes that occur in the wine after alcoholic fermentation and before bottling. In this phase, a series of chemical processes occur, guided by the oenologist, during which the wine periodically meets the air. This contact triggers oxidative reactions that alter the composition of the liquid [18]. The time needed for maturation can vary from a few months to several years based on various factors, such as the type of wine or the materials (wooden or metal) of barrels [17].

Both this phase and the previous one are characterized by a little energy use, since barrels or tanks are typically put in underground rooms, where keeping temperature

and humidity under control is quite easy. This phase, however, requires the use of water to clean barrels or tanks.

2.1.5. Bottling and primary packaging

The bottling of wine is the last stage in the winemaking process, during which the wine is moved from barrels, tanks, or other storage containers into individual glass bottles for sale. This step requires meticulous preparation, filtering, and packaging to maintain the wine's quality, taste, and longevity.

The production of a wine glass bottle is a complex process that requires significant energy consumption. It begins with the collection of raw materials: sand, soda and limestone. These materials are mixed and melted at high temperatures in a furnace, which can reach 1,500°C. This step is highly energetic, since the oven must maintain such a high constant temperature [19]. Once melted, the glass is shaped through various techniques, such as blowing, to obtain the desired shape of the bottle. After shaping, the bottles are cooled in a process known as "*annealing*" which requires additional energy. The energy used in these stages, especially in furnace heating and cooling, makes glass production an energy-intensive process [19].

Primary packaging serves to protect the product inside, secondary packaging facilitates the transportation of goods and must be easily removable to ensure that the primary packaging is not damaged; tertiary packaging refers to packaging that helps producers store and handle goods [20]. In this case, primary packaging is the glass bottle, secondary packaging is the cardboard around the bottles and tertiary packaging is represented by transportation pallets. Nowadays winemakers are increasingly exploring alternative packaging options like bag-in-boxes, Tetra Pak®, PolyEthylene Terephthalate (PET) bottles and cans to help reduce the industry's environmental impact [21]. However, this work will focus only impacts coming from primary packaging, considering the most traditional and diffused way of bottling and packaging in the Italian territory, the single use glass bottle with a cork stopper. The choice of packaging does not rely only on environmental and product conservation aspects, but it is also influenced by consumers' choices. In particular, in Italy, there is widespread skepticism regarding alternative packaging for wine compared to the classic glass bottle [22]. Other than the glass bottles the primary packaging also entails paper labels and plastic components. However, their impact will not be considered in this analysis, since they are minimal compared to those of the glass bottle.

2.1.6. Storage

The storage phase can last some months depending on the previous maturation. During storage, wine continues to evolve at a slower and more controlled pace compared to its time in barrels or tanks. This process generates some changes in wine:

- Bottle maturation, resulting in the evolution of aromas and flavors.
- Micro-oxygenation, where a little part of oxygen can enter the bottle, favoring a little oxygenation that gives the wine its typical color and organoleptic characteristics.
- Stabilization, where any sediment or residue settles at the bottom of the bottle, contributes to the clarity of the wine after their eventual removal.
- Stabilization, where any sediment or residue settles at the bottom of the bottle, contributes to the clarity of the wine after their eventual removal.

The energy use in this phase is very low since bottles are stored in dark, underground rooms.

2.1.7. Distribution

As already stated, this analysis focuses only on the Italian territory and value chain, so impacts related to export and abroad selling are not considered.

On the Italian territory, wine is typically distributed through conventional road transportation methods, such as trucks, since the distances to cover are in the order of hundreds of kilometers.

The distribution phase considered in this research represents the transportation of the full bottles of wine from the producer to the point of sale. Transportation between the previous phases (e.g., transport from the vineyard to the point where maturation takes place; transport of the bottles from the factory to the bottling point, transportation from point of sale to consumers, etc.), will not be considered in this research, since their impacts are minimal compared to distribution.

Around one third of the distribution is in the hands of large scale retailers but includes also the Hotels, Restaurants and Cafè sector (HoReCa), the online selling channels, the wine shops bars [23]. The main environmental impacts generated in this phase comes from fuel consumption and related air emissions.

2.1.8. End of life

The final stage of this value chain refers to the handling of the bottle once the wine has been consumed. This phase evaluates the environmental impact linked to the

management of the bottle, including the energy used and the emissions generated during recycling and disposal.

The impacts related to the collection of waste bottles are not considered in this research.

Glass is an infinitely recyclable material, so recycling glass separately ensures a 100% recyclable resource is kept out of landfills [24]. Reuse of glass bottles from the wine sector is not currently a common practice but, as reported in Section 4.4, all the companies interviewed highlighted that they use recycled glass bottles only.

2.2. Key concepts and functional unit

The purpose of this chapter is to thoroughly define the key concepts and terminology that will be used throughout the thesis, providing a clear understanding of their relevance and application in the context of the research.

2.2.1. Life cycle assessment

To carry out the literature review mainly LCA studies have been considered.

LCA is a widely used and powerful methodology to quantify the environmental impacts of a product or a process and to understand which phases are the most impactful in a life cycle of a product or a commodity.

Following the International Organization for Standardization (ISO) guidelines LCA is composed by four phases: goal and scope definition, inventory analysis, impact assessment and interpretation [25].

LCA focuses on the evaluation of environmental impacts but there are similar methodologies based on life cycle thinking to evaluate economic (life cycle cost) and social (social LCA) sustainability [25]. LCA can also be used by decision-makers across different sectors to implement new policies and adopt practices to enhance value chains' sustainability [26].

As already mentioned, LCA is just one of the many existing tool to address the overall impact of a product, and its focus is mainly on the impacts, while, for example, environmental footprint assessment methods are more pressure oriented [27].

LCA is one of the most used tools in the agri-food field, exploited to increase the environmental performance of various products from this sector [28].

Although it is one of the most complete tools for quantitatively measuring environmental impacts, LCA has also some limitations such as the need for deep know-how, difficulty in gathering data, need to use secondary data that are not always precise, need to make assumptions and difficulty in comparing studies [29].

2.2.2. Hotspot

One of the goals of this work is to identify the environmental hotspot in the Italian wine value chain.

A "hotspot" refers to something that is unusual or out of the ordinary [30].

At the beginning the word "hotspot" was mainly used in the biology sector, to identify geographical areas that are especially abundant in species, contain rare species, endangered species, or have a mix of these characteristics [31] but, nowadays, this term can be extended also to other subjects.

When it comes to "environmental hotspots" in a production or value chain, those can be defined as critical components of the production and consumption cycle regarding

their environmental impacts [32]. Identifying the environmental hotspot in a value chain means looking for the most impactful phase or activity in the chain itself.

Measuring environmental sustainability and therefore identifying environmental hotspots of a process can be crucial for several reasons:

- Improvement of sustainability. The individuation of hotspots can find where the process needs improvement, showing the most effective way to mitigate the overall impact of the chain.
- Cost optimization and waste reduction. Hotspots can also be seen as activities where resources are not perfectly exploited and therefore where surplus costs or waste are generated.
- Social and environmental responsibility. Businesses have a growing responsibility toward sustainability. Neglecting environmental issues and inertia in acting toward improvement practices can damage reputations and drive away customers.
- Regulatory compliance and reduction of sanctions. Many governments and international organizations are implementing stricter regulations related to environmental sustainability.
- Identifying and monitoring hotspots allows the company to anticipate regulatory requirements, avoid fines and improve compliance with international environmental standards.

2.2.3. Carbon footprint and greenhouse gases

CF can be considered as the indicator that quantifies the total amount of direct and indirect GHG emissions associated to all the life cycle of a product, expressed in terms of quantity of equivalent carbon dioxide (CO₂ eq.) [27]. The accumulation of GHGs in the atmosphere is a key factor in climate change, as they trap heat and alter the global climate. The three main GHGs are carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) [33]. Each one of them has a different global warming potential, a measure used to evaluate the potential of each GHG to contribute to global warming, in relation to carbon dioxide. For example, the GWP of the three most relevant GHGs, evaluated according to the IPCC 2013 GWP 100a methodology, are 1, 25, 298 for CO₂, CH₄ and N₂O respectively [34], all expressed as kilograms of CO₂ equivalent on kilograms of that gas [14]. CF is usually one of the impact category calculated with the LCA, corresponding to GHGs emissions [34]. CF, linked with comprehensive environmental LCA methodology can calculate the total emissions across the entire value chain [35].

2.2.4. Water footprint

WF is another crucial indicator for the characterization of environmental hotspots in the wine value chain, it refers to the quantification of the content of water used to produce goods or deliver services [36]. WF is expressed as liters of water used directly (e.g. for irrigation) and indirectly (e.g. for producing pesticides and cleaning wastewater). WF has three components: green, blue and grey. In the specific case of the wine sector, green WF refers to rainwater that is used directly for plant growth, blue WF is linked to water usage in the vineyard for irrigation, washing of vineyard equipment, as well as in the winery for cellar activities and grey WF indicates the volume of water needed to dilute pollutants and restore water quality [37].

The importance of WF is linked to the need of taking consciousness about water content and volumes in products and services. WF is helpful to understand the achievable changes in production systems, markets and also from an agricultural perspective [36].

2.2.5. Evapotranspiration

Evapotranspiration is a fundamental element of the hydrological cycle. The term itself reflects the combination of two processes: evaporation and transpiration. Evaporation is a process through which moisture is transferred from surfaces, such as soil and plant canopies to the air. Transpiration, on the other hand, involves the transformation of liquid water into vapor from the tissues of various parts of the plant, including leaves, stems, flowers, and roots [38].

2.2.6. Functional unit

A FU is a reference measurement that describes the main function of a system or product in a quantifiable and standardized way. FUs are a key aspect of LCA studies as they help in the comparison of different situations or specific cases. For this work, almost all the studies analyzed refer to a FU that is a 0.75 liters glass bottle of wine. Only one of the studies refers to a FU of 1 kg of grapes, as shown in Section 3.4.

3 Methodology

The methodology is divided in two parts. The first part is dedicated to the methodology adopted for the literature review. The narrative and non-systematic approach involves a targeted selection of relevant studies and sources, without following rigid inclusion and exclusion criteria, but to gather an overview as complete and representative as possible of the most recent developments in the field. The quantitative analysis, on the other hand, focuses on the extraction and processing of numerical data from the selected studies, to identify trends, correlations, and significant results [39]. This approach allows a broad and detailed vision of the topic covered.

The second part is dedicated to the methodology adopted for the case study analysis. Interviews were carried out after the literature review was conducted, with the aim of understanding possible solutions (together with their pros and cons) to mitigate the environmental impact of the hotspots determined through the narrative review

3.1. Narrative Review

3.1.1. Selection of papers

To be selected as part of the narrative review, the papers must be referred to case studies carried out on the Italian territory. In the analysis of CF and WF, the selection of papers was carried out with the aim of identifying environmental hotspots. Most of the selected works consist of case studies that offer a detailed and contextualized analysis of environmental footprints. Through case studies, it is possible to fully explore the specific dynamics of the analyzed value chain, providing an accurate understanding of the factors that contribute the most to CF and WF. Furthermore, selected papers that are not presented as direct case studies still refer to the latter, integrating their conclusions through the analysis and interpretation of data collected in real contexts. This combined approach guarantees an overall vision of the problem, enhancing the use of empirical studies to map the critical areas of the value chain. For data collection, mainly scientific articles dealing with LCA were analyzed, with particular attention to those focusing on the assessments of CF and WF. These studies were selected as they offer a systematic and quantifiable assessment of the environmental impacts linked to various processes and activities, providing a

complete picture of the resources consumed and emissions generated. The choice to draw on sources that adopt LCA approaches guaranteed methodological coherence and reliability of the data, allowing the environmental impacts linked to different activities, to be compared and critically analyzed.

In Error! Reference source not found. studies used specifically for CF and WF analysis are shown.

Table 1 - Studies analyzed specifically for CF and WF analysis.

SOURCE	FU	INDICATORS ANALYZED	DESCRIPTION
[37]	0.75 L bottle of wine	CF and WF	Italian red wine case study with a multi-criteria approach to evaluate wine sustainability performance
[40]	0.75 L bottle of wine	CF	Review of CF analysis as an environmental indicator in the wine sector
[41]	0.75 L bottle of wine	CF	Quantitative comparison of the LCA of bottled wines
[27]	0.75 L bottle of wine	CF	Comprehensive and extended analysis of CF data from the Italian wine sector
[42]	0.75 L bottle of wine	CF	CF analysis in the wine industry
[43]	1 kg of grapes	CF	Environmental impact analysis of two different grape varieties for wine production in central Italy
[44]	0.75 L bottle of wine	CF	GHG emissions assessment in the agricultural phase of wine production in the Maremma rural district
[45]	0.75 L bottle of wine	CF	Analysis of environmental performances in wine production by a LCA analysis

[46]	0.75 L bottle of wine	WF	Italian case study with a new approach to assess WF
[14]	0.75 L bottle of wine	CF and WF	CF and WF assessment of an Italian wine bottle
[47]	0.75 L bottle of wine	WF	Italian case study focused on the comparison of Water-focused LCA and WF Assessment
[48]	0.75 L bottle of wine	CF and WF	Italian winery case study with a combination of product environmental footprint method and eco-design process
[49]	0.75 L bottle of wine	CF and WF	Environmental Impact Assessment of an Organic Wine Production in Central Italy: Case Study from Lazio
[50]	0.75 L bottle of wine	Cf and WF	Environmental impact analysis of an organic and biodynamic wine produced in Northeast Italy
[50]	0.75 L bottle of wine	WF	Implementation of an Assessment Methodology and Application to a Case Study for WF
[51]	0.75 L bottle of wine	WF	WF and CF of Wine review and application to a Case Study

From the selected papers, data related to CF and WF were acquired. This choice allowed exploitation of information already validated and collected in the same contexts, thus guaranteeing a solid empirical basis. Collecting data from external sources also facilitated comparative analysis, allowing observations to be validated across a wide range of pre-existing data and increasing the robustness of the results.

To have a complete picture of all the phases (cradle to grave approach), the first phase considered in the research is the one related to the growth of grapes, to conclude with the one related to the disposal of the empty bottle of wine.

The main phases of the value chain studied in this work are shown in *Figure 1*, some smaller phases (e.g. internal transportation of wine bottles within the company or transportation of grapes from the vineyard to the press) are not considered since their environmental impact is negligible if compared to bigger phases.

Exports are not considered in this work, otherwise, the analysis would become too complex given the transport methods and economic variables that would come into play.

Furthermore, this analysis focuses on wine packed in glass bottles since they are the most common and diffused in Italy; some alternatives will be presented but only as possible solutions and will be discussed through the interviews sections of the thesis.

3.1.2. Methodology limitations

Although the methodology adopted, based mainly on the analysis of data from pre-existing studies, presents numerous strengths in terms of reliability and validity, it is important also to recognize some limitations that derive from the type of research that has been conducted.

The main limitation of this research is the difficult comparison of LCA studies. Each LCA study has different assumptions and system boundaries, so the comparison is not always so trivial.

Another important limitation of this research is that it focuses exclusively on the Italian territory. Although this approach allows obtaining specific results contextualized to the characteristics of the Italian wine value chain, the main limitation lies in the fact that the different agricultural realities and practices that characterize viticulture in other countries are not considered. Climatic conditions, production techniques, resource management systems, and environmental regulations vary significantly internationally, and such differences could significantly affect the overall environmental impact of the value chain. Therefore, the results obtained may not be fully applicable to other regions or countries, and this limits the possibility of making direct comparisons with other global wine production realities.

Another limitation of this research comes from the fact that the approach is non-systematic. Unlike systematic reviews, which benefit from well-established guidelines such as the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement, narrative reviews do not have universally acknowledged or standardized guidelines [51]. This lack of standardized guidelines can lead to greater variability in how non-systematic reviews are conducted and reported, making it more difficult to assess their rigor and comprehensiveness compared to systematic reviews. However, despite the absence of formal guidelines, a well-defined search strategy, critical analysis of sources, and transparency in how conclusions are drawn can overcome the intrinsic limits of this approach.

Moreover, the use of secondary data is convenient and time effective but has some structural limitation such as: quality and completeness of the data (the data analyzed were not collected with the same purpose as this research, so some gaps and inaccuracies are inevitable) and bias in the data (data collected from other sources could be influenced by methodological or selection biases, such as the non-representativeness of the sample, which can compromise the validity of the results obtained).

In Section 5, it will be explained how and to what extent these limitations may have influenced the results obtained. This in-depth analysis will allow the contextualization of the conclusions reached, providing a critical and transparent vision of the work carried out and the eventual impacts of its limitations.

3.2. Interviews

As already mentioned, one of the goals of this research is to find environmental hotspots in the Italian wine value chain. This objective was pursued through the analysis of scientific literature, following the methodology explained.

As results of the literature review (see Section 4), the most critical phases from an environmental point of view are the vineyard phase and the production of glass bottles. With the aim of understanding what some alternatives could be to mitigate the environmental impact of these two phases, some interviews were carried out. In addition to the alternatives, interviewees were asked what the problems or limitations of these alternatives are and what the drivers linked to them are.

Semi-structured interviews were carried out, following two surveys each one related to one of the two phases (vineyard and packaging). The two surveys can be found in the appendices of the thesis: survey relating to the vineyard phase is in Appendix A and the one relating to the production of glass bottles is in Appendix B. Surveys are in Italian since all the interviewees were Italians.

Interviewees are of two types:

- a) Wine producing companies, which were asked questions relating to the vineyard phase
- b) Glass producing companies, which were asked questions relating to the production of glass bottles.

Interviewed companies, together with respective interview date, mode, duration, interviewee role and main location of the company are reported in Table 2.

Table 2 - Interviewed companies and interviews' data.

Company name	Date	Mode	Duration	Interviewee role	Location
Cantina Muratori	18/02/2025	Phone call	1 h	Company sustainability officer	Province of Brescia
Vigna Petrusa	05/02/2025	Phone call	1 h	Company sustainability officer	Province of Udine
Glass bottles making company A	04/02/2025	Phone call	1 h	Company sustainability officer	Province of Florence
Glass bottles making company B	04/02/2025	Phone call	1 h	Company sustainability officer	Province of Milan

Interviews were conducted after the literature review phase was completed; interviewees' answers were transcribed during the interview. Results from the interviews and relative comments are in Section 4.4.

4 Results and discussion

The results section begins with a comprehensive assessment of the CF associated with the wine value chain. This analysis quantifies the GHGs emissions based on the selected studies, providing crucial insights into the environmental impact of grape production and wine processing. By evaluating air emissions from different case papers, the goal is to highlight the most significant contributors to the overall CF.

Following the CF assessment, a similar analysis was conducted to evaluate the WF. Through this analysis, a clearer picture emerges in relation to the water resource demands placed by each component of the wine value chain.

In both the CF and WF, the analysis begins by reviewing outputs from existing studies, which provide a foundational understanding of the environmental impacts within the wine value chain. Following this review, attention will turn to analyzing the most impactful phases for each footprint. Finally, in Section 4.3, the study identifies environmental hotspots regarding CF and WF. This involves pinpointing stages within the value chain that disproportionately contribute to environmental impacts. By isolating these key areas, the analysis provides a foundation for developing targeted strategies to mitigate the wine industry's environmental impacts, aligning with broader sustainability goals.

Results coming from the interviews are then reported in Section 4.4.

4.1. Carbon footprint assessment

This section is about the assessment of CF, firstly showing the results from the review of selected studies, and then underlining the critical phases related to this indicator. As explained in Section 2.2.3, CF quantifies the total amount of direct and indirect GHGs emitted and it is expressed as kg of CO₂ equivalent.

Table 3 shows the exact range of CF resulting from the selected studies. Almost all the studies use as FU a 0.75 liters bottle of wine, only one ([43]) refers to a kg of grapes and the ranges are related to that FU.

Table 3 - Ranges of CO₂ equivalent from the studies analyzed.

SOURCE	CF range [kg of CO ₂ eq./FU]
[37]	0.97-1.97
[40]	0.83-3.51
[41]	0.88-6.20
[27]	0.81-1.84
[42]	0.90-2.00
[43]	0.31 (Grechetto grapes) and 0.47 (Sagrantino grapes) kg CO ₂ eq. per kg of grapes
[44]	0.60-1.30
[45]	0.07-0.99

These ranges are only shown to give a general idea about how much CO₂ equivalent is emitted for the production of a wine bottle and are quite in line with each other. However, the variability in emissions, underscores the differences in assumptions, conditions and specific geographical areas in the Italian territory used to assess the CF from the different studies.

In the wine sector, CO₂ equivalent emissions can be attributed mainly to activities such as:

- Pesticides and fertilizers production and use
- Packaging production

- Agricultural practices: any activity that involves the use of agricultural machinery such as harvesting, spreading fertilizers on land and grapes or soil maintenance.
- Transportation
- End-of-life (recycling or disposal)

A case study conducted on 15 different red wines from central Italy, shows a contribution for each phase on the total CF reported in *Figure 2* [37].

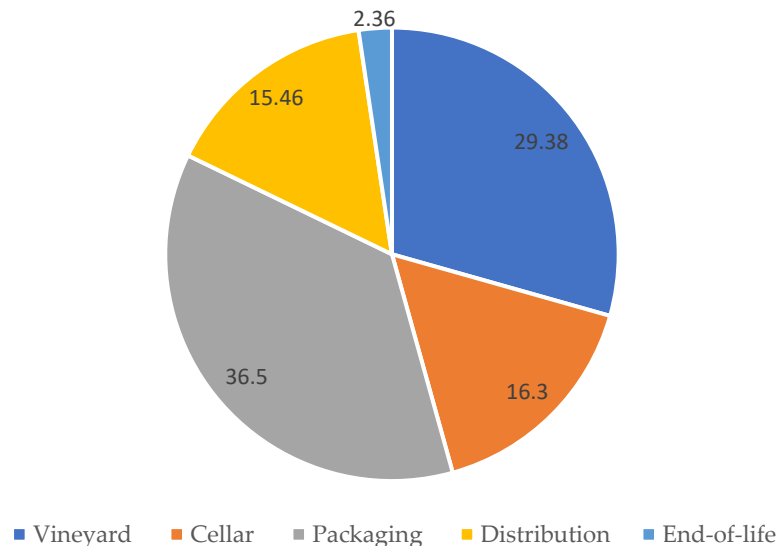


Figure 2 - Contribution on CF of each phase from study [37].

The most contributing phase to the total CF in this case is the packaging phase. More specifically, the packaging production is 36% on the overall CF, while the vineyard phase contributes for 29% and both the cellar and distribution account for 15% more or less [37]. In [37] the end-of-life phase does not account for the disposal of the empty bottle and this could be the reason why it only affects the overall CF for a little percentage. This study specifically used a multi-criteria approach to evaluate different case studies, and underlines the fact that, doing so, and using also other indicators (e.g. the vineyard indicator), will provide a general overview of the impacts coming from each phase, but approaches that follow a single indicator or a single approach, are more accurate when it comes to understanding the exact impact for each phase [37].

Another study([41]), performed a comparison between different case studies. This study, however, grouped the packaging production phase with the end of life phase, showing that only those two phases can contribute up to 70% of the total CF [41].

A third study ([27]) performed a comparison between 16 different wineries with a cradle to grave approach, similarly to study [37], results are shown in *Figure 3*.

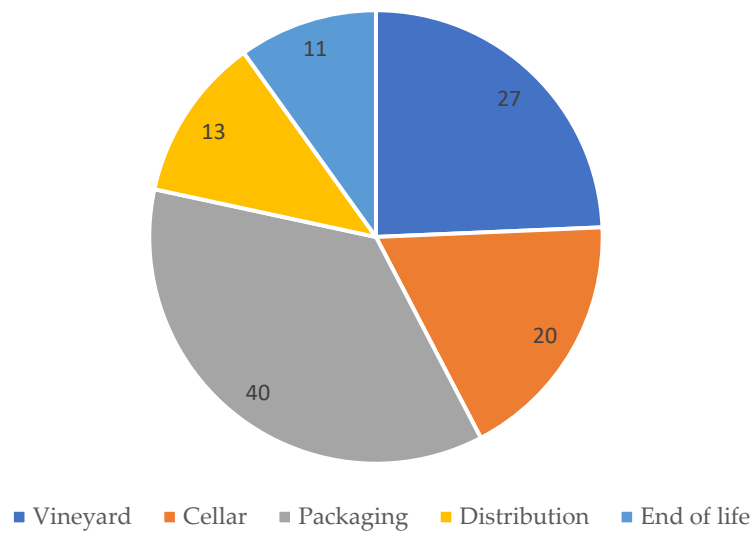


Figure 3 - Contribution on CF of each phase from study [27].

In this study, the disposal of the glass bottle is taken into account, showing that also the end-of-life phase can have significant impact on the overall CF. Again, the packaging production phase is the most impacting one, with 40% on the overall CF, then the vineyard phase with 27% and the storage or cellar phase with 20% [27].

From a case study on a typical Italian red wine produced by a medium-size Umbrian winery ([14]). packaging production and the end of life phase are grouped, similarly to study [41]. The results are in line with the others previously shown and are reported in Figure 4.

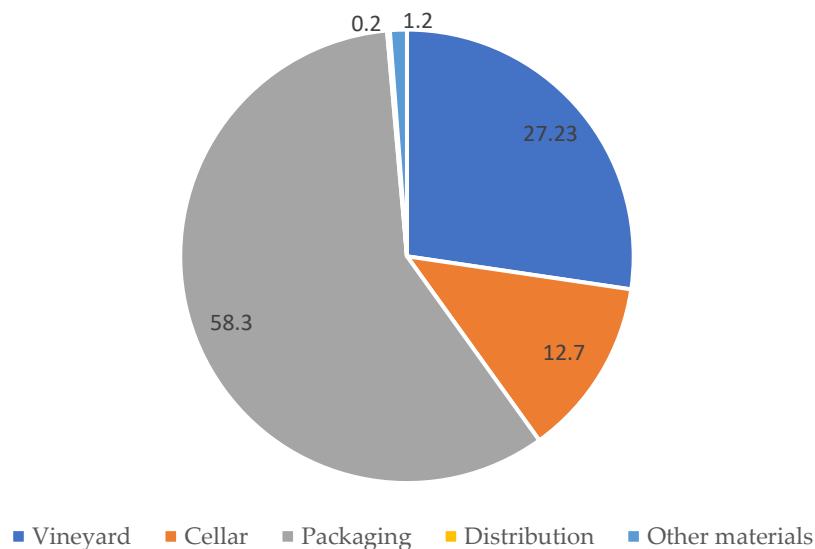


Figure 4 - Contribution on CF of each phase from study [14].

The voice "other materials" refers to the contribution of smaller components such as refrigerants or enzymes [14].

In this case, the dominance of the packaging phase on the overall contribution to the total CF is clear with 58%, The vineyard phase accounts for 27 % and the storage phase for 13% [14]. For this study, distribution was only considered as internal transportation, that's why it only accounts for 0.2% of the total CF [14].

A case study on 4 different wines produced in Italy ([44]), considers the same phases as the ones considered in this research. Results coming from this study are reported in *Figure 5* and are again in line with the others previously shown.

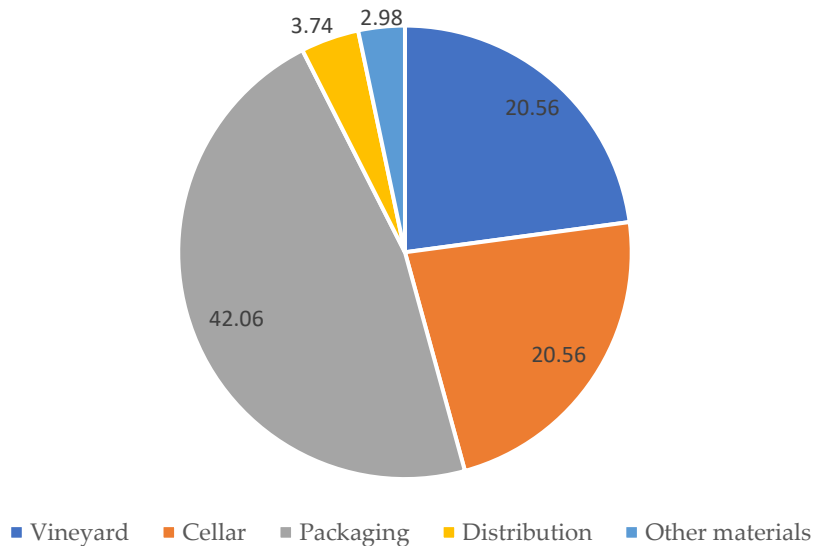


Figure 5 - Contribution on CF of each phase from study [44].

It must be noted that, in this study, the distribution phase refers only to internal distribution and, differently from this thesis, not to the distribution to the sale point. Moreover, the end-of-life phase only refers to the management of the waste and not to its disposal or recycling.

Once again, the packaging production process accounts for the majority of the CO₂ equivalent emitted with 42% on the total CF, vineyard and cellar phase are also relevant with approximately 20% each [44].

In *Figure 6*, minimum and maximum values for the contribution to the total CF (expressed as a percentage) are reported to summarize the results from the studies analyzed. It is clear that the packaging production process is the phase that accounts for CO₂ equivalent emissions the most

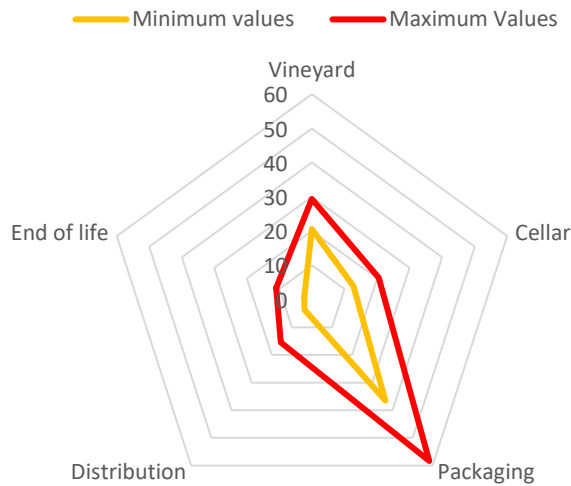


Figure 6 – Graph showing minimum and maximum values from the analyzed studies for the contribution on the total CF for each phase (author's elaboration).

Among the eight studies analyzed specifically for CF, six agree that the phase with the greatest impact on the overall CF is the production of glass bottles.

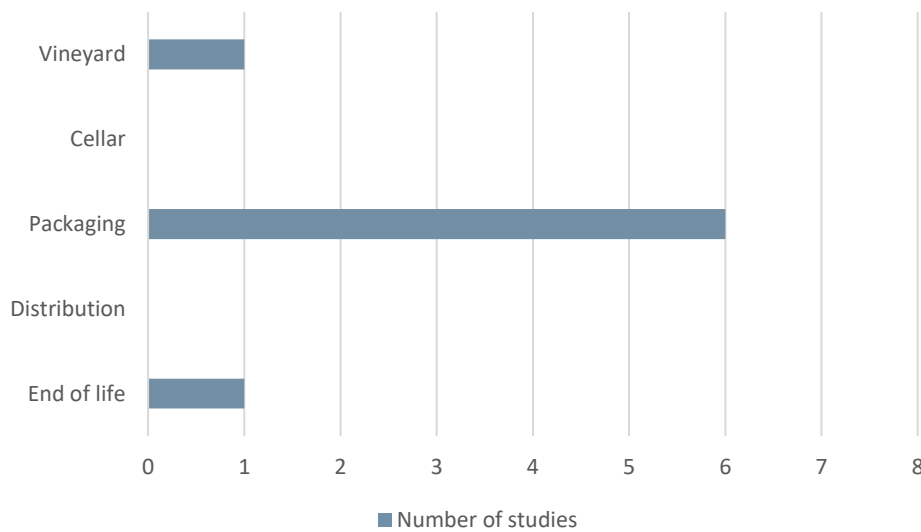


Figure 7 - Number of studies identifying the most critical phase in terms of CF (author's elaboration).

Analyzed studies demonstrate a clear dominance of packaging production when it comes to CF contribution. This dominance remains constant even by changing the system boundaries of the system analyzed between the various studies, revealing that this is the most impactful phase of the value chain with regards to CO₂ equivalent emissions. The CF coming from the production of glass bottles is mainly attributable to the large energy demands (provided mainly by fossil energy carriers), both electrical and thermal, of this process, making it very energy-intensive and with high values of CO₂ equivalent emitted [52].

The vineyard phase, albeit to a lesser extent than that of packaging production, is also a phase that brings a notable contribution to the total CF of this value chain. For this phase, CO₂ equivalent emissions mainly come from diesel combustion, pesticides production and from fertilizers use [53]. Even though the use of pesticides is not deeply analyzed in this study, the latter is a factor that significantly increases CF relating to the vineyard phase, especially if the pesticides used contain Nitrogen or compounds which, even if indirectly contribute to the increase in the CF of the system [41].

Another phase that should be considered for CF in the wine value chain is the cellar or storage phase, but, in this case, CO₂ equivalent emissions are mainly due to electricity production and fugitive emissions [53].

Regarding the distribution phase, the situation is more complex. Some studies, (more specifically studies with system boundaries more in line with this thesis) decree the transport and distribution phase as less impactful and decisive in the total amount of CO₂ equivalent emissions [37], while others attribute higher impacts to distribution [42]. The variety of results for the distribution phase is inevitable, given that the distribution of the bottled product is often in the hands of other actors in the value chain. This means that with the term "distribution", different studies can mean completely different phases and activities, thus producing a wide spectrum of results.

The end-of-life phase is another phase that is not easy to compare between different studies. As already mentioned, some studies group the end-of-life phase with the packaging production, while others, similarly to this thesis, consider this phase as a stand-alone. In both cases, the analysis of different studies suggests that this phase is a non-negligible voice for the total amount of CO₂ equivalent emissions, since, even when the glass is recycled, it requires a selection, cleaning and crushing process that allows to produce new bottles.

In conclusion, the analyzed studies overwhelmingly agree on the fact that the most impactful phase in the life cycle of a bottle of wine is the production of glass bottles. This phase is followed by the vineyard and cellar phase, which contribute significantly to the overall CF. The end-of-life phase and distribution also play a relevant role, although to a lesser extent. These findings highlight the importance of focusing on sustainable solutions to reduce the environmental impact associated with wine packaging production. Those solutions will be explored in Section 4.4.

4.2. Water footprint assessment

This section explores WF assessment in the context of the Italian wine production and value chain. Initially, data acquired from selected studies will be presented, providing an essential overview for understanding the overall WF associated with wine production. Subsequently, a detailed analysis of the wine value chain will be carried out, starting with the examination of the various phases, with the differentiation between green, blue, and grey WF.

Table 4 presents the WF values found in the examined studies, expressed both as point measurements and as estimate intervals. Almost all the studies use as FU a 0.75 liters bottle of wine, only one ([43]) refers to a kg of grapes and the ranges are related to that FU. *Table 4* also shows the production area of the wines from each case study.

Table 4 - Ranges or values of WF from the analyzed studies.

SOURCE	WF range [L of water/FU]	PRODUCTION AREA
[37]	485-826	Northern Italy
[46]	697-701	Northern Italy
[14]	550-610	Central Italy
[54]	632	Central Italy
[43]*	1332-1892	Central Italy

*FU=1 kg of grape

These values are only shown to give a general idea about how much water is needed to produce a single 0.75 liters bottle of wine.

The notable variability of the results is attributable to the fact that, in northern Italy, values of water used for irrigation are much lower than in the center or south. As can be seen in *Table 4*, study [37] (which analyzes wines mainly produced in the north) reports lower values than study [43] (which analyzes wines produced in central Italy and also applies a different FU).

In the wine sector, WF is to be attributed mainly to activities such as:

- Irrigation
- Evapotranspiration
- Application of fertilizers or pesticides
- Cleaning, washing consumptive water use [54].

The case study on a typical Italian red wine produced by a medium-size Umbrian winery ([14]) groups packaging production and end-of-life phase together. Contributions of each phase on the total WF are shown in *Figure 8*.

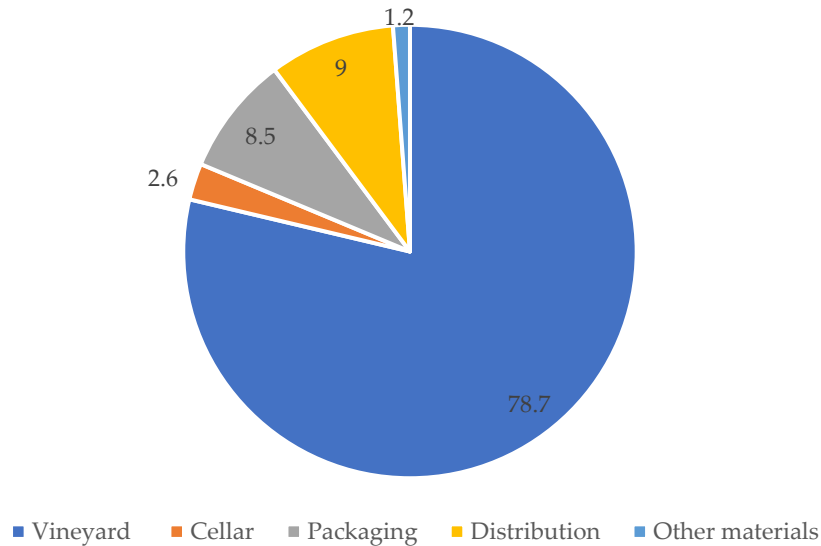


Figure 8 - Contribution on WF of each phase from study [14].

The vineyard phase absolutely impacts the most if we consider WF with 79%, while distribution, packaging and cellar phase account only for 9%, 8% and 3% respectively[14].

A case study ([47]) where the distribution phase is not considered, and the relative contribution of vineyard, cellar and packaging phase is shown in *Figure 9*.

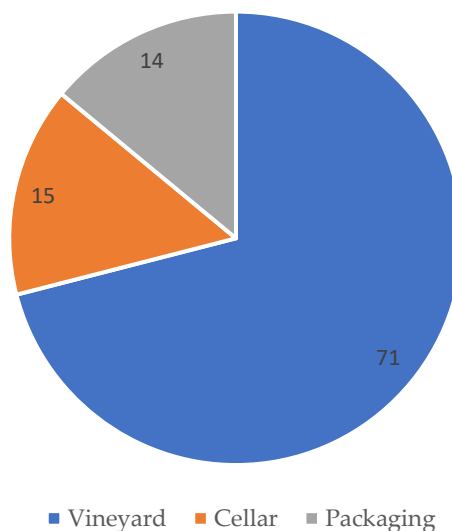


Figure 9 - Contribution on WF of each phase from study [47].

In this research the vineyard phase is the most impacting one in terms of WF with 71%, followed by cellar and packaging phase with 15% and 14% respectively.

A review of the WF methodology for a red and a white wine produced by the same company ([55]) shows results that are again in line with the ones previously reported, as can be seen from *Figure 10*. Distribution in this case was considered only as internal transportation; that's why its contribution to the total WF is negligible.

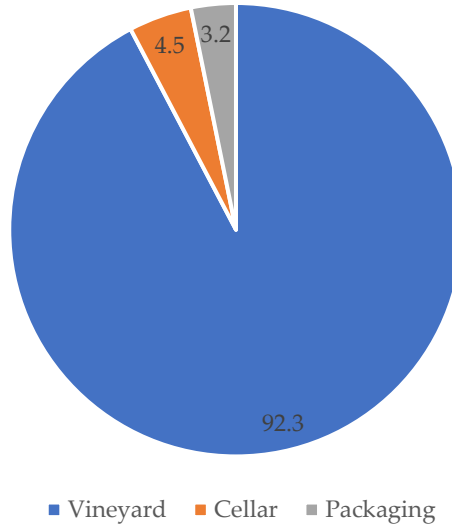


Figure 10 - Contribution on WF of each phase from study [55].

Again, WF is almost entirely associated with the vineyard phase with 92%, followed by the cellar and packaging phase with 5% and 3% respectively.

Even if it is evident that the hotspot, from a WF perspective, is the vineyard phase, it is necessary to understand what components of the WF are causing the vineyard phase to be this water consuming, in order to comprehend where wine producers could focus to reduce water consumption from this phase. As explained in section 2.2.4, WF is the sum of three components: green WF, blue WF and grey WF. Understanding which components are the most critical is useful to identify possible mitigation actions.

Values for blue WF can vary a lot between different case studies, considering different irrigation techniques or systems, different climatic conditions and different cultivation methods.

For the vineyard phase, green WF accounts for the biggest part of the total WF with 90%, followed by grey WF with 9% and blue WF with only 0.4% [14], as shown by *Figure 11*.

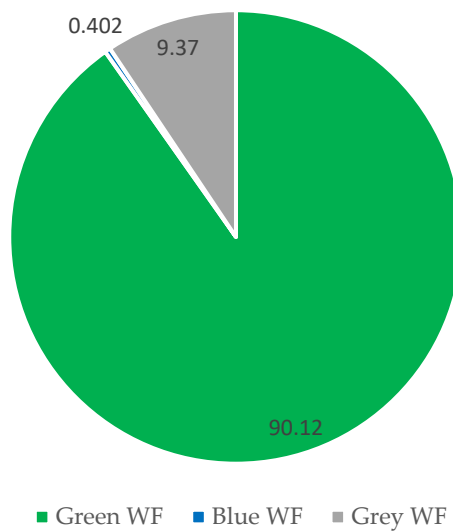


Figure 11 - Relative contribution of Green, blue and grey WF in the vineyard phase from study [14].

Another study ([47]) instead reports different values for blue WF (16%) and grey WF (1%), while green WF (83%) remains the dominant contributor to WF in the vineyard phase, as shown in Figure 12.

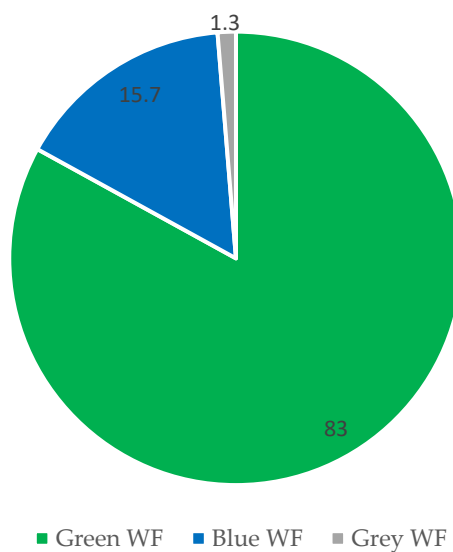


Figure 12 - Relative contribution of Green, blue and grey WF in the vineyard phase from study [47].

However, another study ([55]) shows that, even with different assumptions and system boundaries, green WF still impacts the most on the overall WF in the vineyard phase with 89%, followed by grey WF with 8% and blue WF with 1%, as showed by Figure 13.

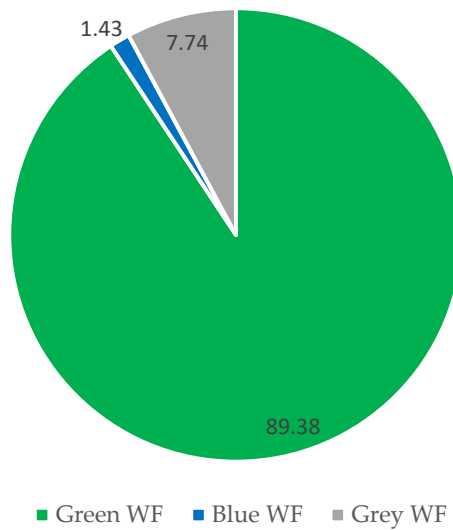


Figure 13 - Relative contribution of Green, blue and grey WF in the vineyard phase from study [55].

WF derives mainly from the very early stages of the wine production chain, particularly from the vineyard phase, followed with much lesser extents by the cellar and the packaging phase. Even comparing different case studies with different system boundaries, assumptions and methodologies used, the green component is the one that has the greatest impact on the WF of the vineyard phase and, also, on the overall WF of the wine value chain. These findings highlight the importance of focusing on sustainable alternatives to reduce the WF associated with the vineyard phase. Those alternatives will be explored and discussed in Section 4.4.

4.3. Summary of results from narrative review

In this section, hotspots within the Italian wine value chain are assessed.

This assessment will provide an overview of the identified critical areas as far as CF and WF, related to the results reported in the previous sections.

The main hotspots in the Italian wine value chain, according to the analyzed literature, are two:

1. The vineyard phase
2. The packaging production phase.

For the vineyard phase, it is highlighted by the analysis of WF along the value chain that this phase is clearly a hotspot. The fact that it is a hotspot is very evident, as the studies analyzed highlight that the amount of water consumed in the vineyard phase of this value chain is decidedly greater compared to the water required by other stages.

The contribution of other phases to the total WF of the value chain appears to be almost negligible compared to that of the vineyard one, however, it should be underlined that the green WF, depicted as the biggest contributor to the overall WF in the vineyard phase, is given by the evapotranspiration, that is a natural phenomenon.

In the Interviews results section, some alternatives to mitigate evapotranspiration will be reported and discussed, all coming from interviews carried out with people from winemaking companies.

For the packaging production phase, on the other hand, this environmental hotspot comes to light through an analysis of the CF of the value chain in question, its impact, as highlighted by the analyzed literature, is in fact the most decisive on the total CF of the chain. Furthermore, the vineyard, distribution and end-of-life phases still appear to have a significant impact on the total CF, even if to a lesser extent than the phase just defined as hotspot.

Critical issues arising from the production of glass bottles are linked to the high energy consumption and CO₂ equivalent emissions resulting from this process, as already explained in Background section.

Similarly to the first hotspot, in Section 4.4, some alternative packaging will be reported and discussed, all coming from interviews carried out with glassmaking companies, to understand their pros and cons.

4.4. Interviews results

After the results from the narrative literature review were discussed in the previous Sections, this Section shows the results coming from the interviews conducted, as explained in Section 3.2. The interviews are aimed at defining alternatives to mitigate the hotspot assessed through the literature. In addition to the possible alternatives, the interviews also had the aim of understanding the limits and drivers linked to each alternative.

As regards the WF, the alternatives are aimed at mitigating evapotranspiration (vineyard phase), while as regards CF, the alternatives are aimed at mitigating emissions of CO₂ equivalent in the packaging phase. Results from the interviews for the vineyard phase hotspot are reported in **Error! Reference source not found.**

Table 5 - Results from interviews for the vineyard hotspot.

Solution	Pros	Cons
Foliar coverage through the mineral kaolin	Cheap Higher solar reflection	Problems related to high temperatures
Covers of different colors on the vineyard	Useful also as protection from extreme weather events	Excessive shading Technique still under development
Choice of plants varieties with more leaves	Temperature and humidity under control	Problems with shading where there is a high bunches density
Drip irrigation systems	Useful also to reduce blue WF	Expensive Complex design
Mulching	Cheap	Problems if irrigation is done through sprinklers or rain methods

The first three solutions aim at directly decreasing the transpiration coming from leaves, while the last two aim at decreasing the evaporation coming from the soil. The possible solution individuated are:

- Foliar coverage through the mineral kaolin. Kaolin is a white mineral, which can be put on the upper part of the leaf to protect the lower part (the part responsible for plant transpiration). This process is done through sprayers, and it creates a cover on the upper part of the leaf, doing so, the amount of solar radiation that is reflected increases. With the increment of solar reflection, temperature and humidity are more stable and, as a consequence, the plant transpires less from the stomata in the lower part of the leaf. Kaolin is quite cheap, and it is much used especially in small or medium vineyards, but the application of this mineral can have some drawbacks. When temperatures are very high, especially from mid-June up to the harvest period, the excessive coverage of leaves can increase the humidity in the leaves zone exponentially. If the temperature, and thus the humidity increases too much, the effect produced is the opposite: leaves transpire more and the green WF increases.
- Covers of different colors on the vineyard itself. This solution provides coverage of different colors (red, green or blue) on the whole vineyard (a sort of roof) at approximately 3.5/4 meters, to protect plants from excessive solar radiation and also from extreme weather events that are more and more frequent. The pros of this solution are the same as the previous one, but this solution is still under development (especially for the choice of color), and it is not cheap since the implementation of it requires an accurate design and sizing process and is not particularly suitable for large vineyards or vineyards that are located on slopes. Furthermore, during cloudy days, this solution can produce excessive shading, as a consequence vines cannot receive enough solar radiation to carry out photosynthesis, affecting grapes quality and quantity. One of the interviewed companies is trying to implement automated covers on some of its vineyards. This solution aims at opening the covers during cloudy days and closing them when the solar radiation is too high.
- Choice of vines that have a higher leaves density around the bunches of grapes. The choice of plants, however, is something that is done before the planting phase, when the company selects the varieties of grapes that it wants to produce. This solution produces the same effects as the application of Kaolin on leaves and is used to keep temperature and humidity under control around the grapes. The main drawback of this solution is that, when leaves density is too

high, this can produce an excessive shading on the grapes, that are not able to develop properly.

- Drip irrigation systems. These systems are exploited to decrease the evaporation component of evapotranspiration coming from the soil. This type of irrigation is part of micro-irrigation systems and aims at feeding water directly into the root zone of the vines, to minimize water losses due to evaporation. This process affects both the green and blue WF, since the amount of water needed for this type of irrigation is much smaller than the one needed for traditional irrigation systems. However, this solution is expensive and requires a design process, furthermore, it is not suitable for large vineyards.
- Mulching. This solution refers to the covering or spreading of some materials on the ground to protect soil and crops from excessive sun radiation. This process is done either with sheets made of polyethylene or natural materials (e.g. barks or dead leaves). Mulching is a cheap solution to minimize soil evaporation, however, it should not be paired with rain irrigation methods, and the amount of material on the soil should still let the upper level of the soil exchange substances with the atmosphere.

For the packaging production hotspot, results from the interviews are collected in **Error! Reference source not found.** Since the companies interviewed are glass producers, the solutions most investigated for this hotspot are still linked to the production of glass, those not linked to this production are the result of an interview with one of the wine producing companies, which also deals with the sale of it.

Table 6 - Results from interviews for the packaging hotspot.

Solution	Pros	Cons
Recycled glass	Less raw materials Less energy use	Variable quality Collection and selection costs
Lightened glass	Weight reduction Less energy use	Quality perception Compatibility with bottling machinery
PET bottles	Weight reduction Unbreakability	Quality perception Reduction of the oxygen barrier
Aluminum bottles	Weight reduction Oxygen barrier kept	Quality perception Interactions with wine

Even though almost all companies producing glass bottles now use recycled glass, the advantages and disadvantages have been highlighted to have a comparison with non-recycled glass. After the bottles are collected, they are divided by color and crushed into small pieces, these pieces are then melted down and shaped into new bottles. This process offers some advantages such as the need for less raw materials and less energy to be produced. Glass can be endlessly recycled, making it a highly sustainable and material. Benefits of using recycled glass are obvious, however, there can be some problems arising from it. First of all, the quality and purity of recycled glass can be variable, affecting the color of the bottles and, as a consequence, the interaction with wine can be compromised. Secondly, the production of recycled glass requires a collection and selection process that needs adequate infrastructure and technologies; this process is then quite expensive.

Regarding the use of lightened glass, not yet cleared through customs in this value chain, it has some pros like the reduction in energy consumption and the reduction of the weight of the bottle, that helps decreasing the emissions coming from the distribution process too. However, drawbacks from the use of lightened glass are:

- Quality perception: consumers, especially in Italy are quite skeptical when it comes to different wine packaging and in this case the light weight of the bottle could produce questions relating to the quality of the bottled wine
- Compatibility with already existing bottling machinery: not all bottling and packaging equipment may be immediately compatible with lightweight glass.

As already mentioned, also some alternatives not related to glass have been analyzed:

- PET bottles, for example, are lighter and more resistant compared to glass, so emissions related to transportation can decrease. On the other hand, PET bottles, other than affecting the quality perception of the product, also have a weaker oxygen barrier and thermal stability compared to glass bottles, as a consequence, wine characteristics could be compromised.
- Aluminum bottles are already in use in some markets (e.g. in northern Europe countries) for soft drinks and also for wine and are a valid alternative to glass bottles. The main pros deriving from the use of aluminum are that, even if the weight of the bottles is lower, they are very resistant and are able to keep the oxygen barrier. Furthermore, the aluminum recycling process does not affect its quality, making it a very environmentally friendly material. Aluminum bottles, however, are not a common packaging for wine, and Italian consumers are wary of this type of packaging for products like wine. Moreover, aluminum has high thermal conductivity and can interact with the bottled wine, as a consequence, the bottle could interact with wine, altering its flavor and aroma.

One of the wine producing companies that were interviewed pointed out that also other components of the primary packaging needs to be accounted when it comes to sustainability. For example, different types of stoppers are being investigated compared to the classic cork one. One of the alternatives could be the screw cap, already used for some type of wine, but with quality perception problems and not suitable for all kinds of wine.

Some of these solutions, even if they help to mitigate one of the two indicators analyzed, could worsen the other. For example, mulching, if done with polyethylene, helps for the WF but significantly increases the CF.

It is also important to underline that all the solutions and alternatives presented in this section are mainly suitable for small or medium-sized wineries, therefore, they could be appropriate for the Italian scenario given the context, explained in section 1.

5 Conclusion

Starting from the research questions outlined in the Introduction, the aim of this thesis was to address the first question through a narrative review of the scientific literature whereas, for the second question, interviews with wine producers and other stakeholders in this value chain were performed.

The literature review process of this thesis focused on analyzing the topic by examining relevant scientific articles, particularly focusing on CF and WF. Furthermore, interviews were conducted to gain insights into the techniques employed to alleviate the critical issues identified in the literature, together with their advantages and disadvantages.

From the literature review, it clearly emerged that the vineyard phase turned out to be crucial for the WF. Likewise, with regards to the CF, the packaging production phase appears to be a critical point that deserves particular attention. Recognizing and addressing these aspects can help improve the sustainability of the entire value chain, offering ideas for future research and greener practices.

As regards the interviews, the results showed a variety of alternatives that can be used by producers (of both wine and glass) to mitigate the hotspots highlighted through the analysis of the literature, revealing also their positive and negative effects.

This thesis is of significant importance in the analysis of environmental hotspots within the wine value chain, as it provides an in-depth understanding of the ecological pressures that characterize this sector. Through an exhaustive review of the literature, critical points have been identified that require targeted interventions to improve sustainability. The integration of interviews with wine producers and other value chain actors further enriches the research, offering practical perspectives on how to mitigate these impacts.

This multidimensional approach not only enhances the importance of environmental sustainability in the wine sector but also represents a starting point for future initiatives and strategies aimed at promoting a more responsible and aware wine economy.

5.1. Generalizability

In this section, the ability to extend the results obtained to broader contexts than the specific one analyzed is examined.

It is important to underline that pre-existing studies were used, which collected a high number of case studies, helping to create a representative and robust picture of the reality of the Italian wine value chain. This solid evidence base allowed to draw conclusions that not only apply to the specific research context but also offer significant insights for the entire wine sector. Critical analysis of generalizability is therefore essential to understanding the impact and broader implications of the study's findings.

It is also important to highlight that, although the situation of the Italian wine value chain presents unique and specific characteristics, the results obtained can still be extended to other similar contexts, such as those of France or Spain. These countries share similar economic, cultural and production factors, which make the application of the conclusions emerging from the research relevant. Therefore, understanding the dynamics analyzed in Italy could offer useful and applicable ideas also at an international level, encouraging a comparison and exchange between the different wine-growing realities.

In conclusion, even if this study has some limitations, it is able to provide a general picture representative of the current situation relating to environmental hotspots along the Italian wine value chain.

5.2. Limitations and future developments

Understanding the limitations is critical not only to evaluate the validity of the research, but also to guide future studies in this field. Through a critical analysis of the challenges faced, a more complete vision of the work carried out is offered, fueling a reflection on the need for further in-depth analysis and methodological improvements.

The first limitation of this thesis derives from the process itself used to conduct it: the studies analyzed for the analysis of the topic were found without a standardized methodology but only through a non-systematic search for scientific papers that dealt with this subject. Using a standardized research and review methodology has the advantage that it is a process that is easily repeatable over time, and therefore, finding new studies with the same method can be useful for staying updated on the results and comparing them with studies previously carried out in this way.

The second limitation of this study lies in the fact that only two indicators are analyzed (CF and WF). The analysis of more indicators can guarantee a more faithful

representation of the environmental situation of the value chain taken into consideration.

The third main limitation of this work lies in the fact that the value chain considered has been decidedly simplified, with the aim of arriving at an overview that is as real and representative as possible.

Despite the limitations of the thesis, it represents a general framework regarding the hotspots in the Italian wine value chain from an environmental perspective.

In the conclusion of this thesis, an important perspective opens up for future research developments in the field of wine value chain sustainability. It will be essential to further deepen the analysis of environmental hotspots, exploring not only the aspects already identified, but also other potential impact factors that can affect sustainability. Furthermore, future research could focus on the implementation of the mitigation techniques suggested by the interviewees, evaluating their effectiveness and practicability in a real context. Finally, the integration of interdisciplinary methodologies and collaborations between different actors in the sector is desirable, in order to develop innovative and shared strategies that address environmental challenges more effectively, contributing to a more sustainable future for the Italian wine value chain.

Bibliography and webography

- [1] H. Ritchie, P. Rosado, and M. Roser, "CO₂ and Greenhouse Gas Emissions," *Our World in Data*, Dec. 2023, <https://ourworldindata.org/co2-and-greenhouse-gas-emissions>.
- [2] European commission, "swd-annual-single-market-report-2021_en.pdf.", 2021, https://commission.europa.eu/system/files/2021-05/swd-annual-single-market-report-2021_en.pdf.
- [3] M. Karwacka, A. Ciurzyńska, A. Lenart, and M. Janowicz, "Sustainable Development in the Agri-Food Sector in Terms of the Carbon Footprint: A Review," *Sustainability*, 12(16), 6463, Aug. 2020, doi: 10.3390/su12166463.
- [4] G. Maesano, M. Milani, E. Nicolosi, M. D'Amico, and G. Chinnici, "A Network Analysis for Environmental Assessment in Wine Value Chain," *Agronomy*, 12(1), 211, Jan. 2022, doi: 10.3390/agronomy12010211.
- [5] R. di Rainews, "L'Italia è il maggior produttore di vino al mondo," RaiNews. Accessed: Oct. 17, 2024, <https://www.rainews.it/articoli/2022/01/litalia--il-maggior-produttore-di-vino-al-mondo-0c835c3c-f01b-4f00-b31a-7b55bf9d489a.html>
- [6] "La produzione di vino in Italia nel 2023 – dati provvisori ISTAT | I numeri del vino.", 2022, <https://www.inumeridelvino.it/2024/04/la-produzione-di-vino-in-italia-nel-2023-dati-provvisori-istat.html>.
- [7] ISTAT, "7 Censimento generale.", 2024, <https://www.istat.it/statistiche-per-temi/censimenti/agricoltura/7-censimento-generale/>.
- [8] A. Casson, B. Ortuani, V. Giovenzana, L. Brancadoro, S. Corsi, O. Gharsallah, R. Guidetti, A. Facchi, "A multidisciplinary approach to assess environmental and economic impact of conventional and innovative vineyards management systems in Northern Italy", *Science of The Total Environment*, 838, 156181, Sep. 2022, doi: 10.1016/j.scitotenv.2022.156181.
- [9] L. Cecchini, B. Torquati, and M. Chiorri, "Sustainable agri-food products: A review of consumer preference studies through experimental economics," *Agric. Econ. - Czech*, 64(12), 554–565, Dec. 2018, doi: 10.17221/272/2017-AGRIC ECON.
- [10] M. Christopher, *Logistics and Value Chain Management: Strategies for Reducing Costs and Improving Services*, Financial Times, London, 1992.

- [11] A. Feller, D. Shunk, T. Callarman, "Value Chains Versus Supply Chains", *BP trends*, 1(3), 165-173, March 2006.
- [12] E. Pomarici, A. Corsi, S. Mazzarino, R. Sardone, "The Italian Wine Sector: Evolution, Structure, Competitiveness and Future Challenges of an Enduring Leader," *Ital Econ J*, 7(2), 259–295, Jul. 2021, doi: 10.1007/s40797-021-00144-5.
- [13] Ismea Mercati, "Vino - I numeri del settore"
<https://www.ismeamercati.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/4051>.
- [14] E. Bonamente, F. Scrucca, S. Rinaldi, M. C. Merico, F. Asdrubali, and L. Lamastra, "Environmental impact of an Italian wine bottle: Carbon and water footprint assessment", *Science of The Total Environment*, 560–561, 274–283, Aug. 2016, doi: 10.1016/j.scitotenv.2016.04.026.
- [15] Caviro Extra, "Caviro Extra: ricavati della filiera vitivinicola e agroalimentare", 2025, <https://caviroextra.it/>.
- [16] E. Cappa, "Come si fa il vino? Tutti i passaggi | Callmewine", 2024, <https://www.callmewine.com/blog/wine-academy/how-to/come-si-fa-il-vino-dalla-raccolta-all-imbottigliamento/>.
- [17] P. Petrilli, "Scopri la differenza tra vino rosso e vino bianco", <https://www.paolopetrilli.it/articoli-blog/vino-rosso-e-vino-bianco-qual-e-la-differenza/>.
- [18] MyWonderWine, "Maturation and Aging of Wine", 2024, <https://mywonderwine.co.uk/blogs/blog/maturation-and-aging-of-wine>.
- [19] Vetrolab, "Come si produce una bottiglia di vetro", 2024, <https://www.vetrolab.com/it-it/come-si-produce-una-bottiglia-di-vetro.aspx>.
- [20] J. Shin, S. E. M. Selke, "Food Packaging", *Food Processing*, 1, 249–273, 2014, doi: 10.1002/9781118846315.ch11.
- [21] A. Mierczynska-Vasilev, "The future of wine packaging – A perspective", *Sustainable Agriculture and Environment*, 1(1), 3-12, Apr. 2024, doi: 10.24294/sae.v1i1.3506.
- [22] C. Ferrara, V. Zigarelli, and G. De Feo, "Attitudes of a sample of consumers towards more sustainable wine packaging alternatives", *Journal of Cleaner Production*, 271, 122581, Oct. 2020, doi: 10.1016/j.jclepro.2020.122581.
- [23] Mediobanca, "Report Mediobanca: i canali di vendita de vini italiani nel 2023", 2024, <https://www.beverfood.com/report-mediobanca-i-canali-vendita-de-vini-italiani-2023-wd/>.
- [24] WasteNot Compost, "Importance of Glass Recycling", 2025, <https://www.wastenotcompost.com/blogs/importance-of-glass-recycling>.

- [25] International Organization for Standardization, "ISO 14044:2006(en), Environmental management – Life cycle assessment – Requirements and guidelines", 2024, <https://www.iso.org/obp/ui/en/#iso:std:iso:14044:ed-1:v1:en:fn:1>.
- [26] R. Alhashim, R. Deepa, and A. Anandhi, "Environmental Impact Assessment of Agricultural Production Using LCA: A Review", *Climate*, 9(11), Nov. 2021, 5-18, doi: 10.3390/cli9110164.
- [27] D. D'Ammaro, E. Capri, F. Valentino, S. Grillo, E. Fiorini, L. Lamastra, "Benchmarking of carbon footprint data from the Italian wine sector: A comprehensive and extended analysis", *Science of The Total Environment*, 779, 146416, Jul. 2021, doi: 10.1016/j.scitotenv.2021.146416.
- [28] B. Notarnicola, R. Salomone, L. Petti, P. A. Renzulli, R. Roma, A. K. Cerutti, *Life Cycle Assessment in the Agri-food Sector: Case Studies, Methodological Issues and Best Practices*, Springer, 2015.
- [29] M. A. Curran, "Strengths and Limitations of Life Cycle Assessment", *Background and Future Prospects in Life Cycle Assessment*, Dordrecht: Springer Netherlands, 2014, pp. 189–206. doi: 10.1007/978-94-017-8697-3_6.
- [30] R. G. Gurao, "Some Procedures For Identifying Hotspots".
- [31] W. V. Reid, "Biodiversity hotspots" *Trends in Ecology & Evolution*, 13(7), 275–280, Jul. 1998, doi: 10.1016/S0169-5347(98)01363-9.
- [32] V. Castellani, S. Sala, and L. Benini, "Hotspots analysis and critical interpretation of food life cycle assessment studies for selecting eco-innovation options and for policy support", *Journal of Cleaner Production*, 140, 556–568, Jan. 2017, doi: 10.1016/j.jclepro.2016.05.078.
- [33] M. Brander, "Greenhouse Gases, CO₂, CO₂e, and Carbon: What Do All These Terms Mean?", *Econometrica*, 2-3, 2012.
- [34] Intergovernmental Panel On Climate Change, "Global-Warming-Potential-Values (August 2024)", 2024, <https://ghgprotocol.org/sites/default/files/2024-08/Global-Warming-Potential-Values%20%28August%202024%29.pdf>.
- [35] B. P. Weidema, M. Thrane, P. Christensen, J. Schmidt, S. Løkke, "Carbon Footprint", *Journal of Industrial Ecology*, 12(1), 3–6, 2008, doi: 10.1111/j.1530-9290.2008.00005.x.
- [36] H. S. Matthews, C. T. Hendrickson, C. L. Weber, "The Importance of Carbon Footprint Estimation Boundaries" *Environ. Sci. Technol.*, 42(16), 5839–5842, Aug. 2008, doi: 10.1021/es703112w.

- [37] D. Lovarelli, J. Bacenetti, and M. Fiala, "Water Footprint of crop productions: A review", *Science of The Total Environment*, 548–549, 236–251, Apr. 2016, doi: 10.1016/j.scitotenv.2016.01.022.
- [38] D. D'Ammaro, E. Capri, F. Valentino, S. Grillo, E. Fiorini, L. Lamastra, "A multi-criteria approach to evaluate the sustainability performances of wines: the Italian red wine case study", *Science of The Total Environment*, 799, 149446, Dec. 2021, doi: 10.1016/j.scitotenv.2021.149446.
- [39] P. R. A. Krishna, "Evapotranspiration and agriculture-A review", vol. 40(1), 2019, doi: 10.18805/ag.R-1848.
- [40] Investopedia, "Quantitative Analysis (QA): What It Is and How It's Used in Finance", 2024, <https://www.investopedia.com/terms/q/quantitativeanalysis.asp>.
- [41] B. Rugani, I. Vázquez-Rowe, G. Benedetto, E. Benetto, "A comprehensive review of carbon footprint analysis as an extended environmental indicator in the wine sector", *Journal of Cleaner Production*, 54, 61–77, Sep. 2013, doi: 10.1016/j.jclepro.2013.04.036.
- [42] M. Jourdain, P. Loubet, S. Trebucq, G. Sonnemann, "A detailed quantitative comparison of the life cycle assessment of bottled wines using an original harmonization procedure", *Journal of Cleaner Production*, 250, 119472, Mar. 2020, doi: 10.1016/j.jclepro.2019.119472.
- [43] F. Scrucca, E. Bonamente, and S. Rinaldi, "Chapter 7 - Carbon Footprint in the Wine Industry", *Environmental Carbon Footprints*, S. S. Muthu, Ed., Butterworth-Heinemann, 2018, 161–196. doi: 10.1016/B978-0-12-812849-7.00007-6.
- [44] P. Bartocci, P. Fantozzi, F. Fantozzi, "Environmental impact of Sagrantino and Grechetto grapes cultivation for wine and vinegar production in central Italy - ScienceDirect", 140(2), 569-580, 2017, doi: 10.1016/j.jclepro.2016.04.090.
- [45] S. Bosco, C. Di Bene, M. Galli, D. Remorini, R. Massai, and E. Bonari, "Greenhouse gas emissions in the agricultural phase of wine production in the Maremma rural district (Tuscany, Italy)", 2011, doi: 10.4081/ija.2011.e15.
- [46] R. Iannone, S. Miranda, S. Riemma, I. De Marco, "Improving environmental performances in wine production by a life cycle assessment analysis - ScienceDirect", *Journal of cleaner production*, 111(A), 172-180, 2016, doi: 10.1016/j.jclepro.2015.04.006.
- [47] L. Lamastra, N. A. Suci, E. Novelli, M. Trevisan, "A new approach to assessing the water footprint of wine: An Italian case study" *Science of The Total Environment*, 490, 748–756, Aug. 2014, doi: 10.1016/j.scitotenv.2014.05.063.

- [48] E. Borsato, E. Giubilato, A. Zabeo, L. Lamastra, P. Criscione, P. Tarolli, F. Marinello, L. Pizzol, "Comparison of Water-focused Life Cycle Assessment and Water Footprint Assessment: The case of an Italian wine - ScienceDirect", *Science of total environment*, 666, 1220-1231, 2019, doi: 10.1016/j.scitotenv.2019.02.331.
- [49] A. Manzardo, A. Marson, F. Zuliani, J. Bacenetti, and A. Scipioni, "Combination of product environmental footprint method and eco-design process according to ISO 14006: The case of an Italian winery" *Science of The Total Environment*, 799, 149507, Dec. 2021, doi: 10.1016/j.scitotenv.2021.149507.
- [50] G. Vinci, S. A. Prencipe, A. Abbafati, M. Filippi, "Environmental Impact Assessment of an Organic Wine Production in Central Italy: Case Study from Lazio", *Sustainability*, 14, (22), Jan. 2022, doi: 10.3390/su142215483.
- [51] P. Masotti, A. Zattera, M. Malagoli, P. Bogoni, "Environmental Impacts of Organic and Biodynamic Wine Produced in Northeast Italy" *Sustainability*, 14(10), 6281, May 2022, doi: 10.3390/su14106281.
- [52] R. Ferrari, "Writing narrative style literature reviews", *Medical Writing*, 24(4), 230–235, Dec. 2015, doi: 10.1179/2047480615Z.000000000329.
- [53] M. Zier, P. Stenzel, L. Kotzur, D. Stolten, "A review of decarbonization options for the glass industry", *Energy Conversion and Management: X*, 10, 100083, Jun. 2021, doi: 10.1016/j.ecmx.2021.100083.
- [54] L. Pinto da Silva and J. C. G. Esteves da Silva, "Evaluation of the carbon footprint of the life cycle of wine production: A review", *Cleaner and Circular Bioeconomy*, 2, 100021, Aug. 2022, doi: 10.1016/j.clcb.2022.100021.
- [55] E. Bonamente, F. Scrucca, F. Asdrubali, F. Cotana, A. Presciutti, "The Water Footprint of the Wine Industry: Implementation of an Assessment Methodology and Application to a Case Study", *Sustainability*, 7(9), Sep. 2015, doi: 10.3390/su70912190.
- [56] S. Rinaldi, E. Bonamente, F. Scrucca, M. C. Merico, F. Asdrubali, and F. Cotana, "Water and Carbon Footprint of Wine: Methodology Review and Application to a Case Study", *Sustainability*, 8(7), Jul. 2016, doi: 10.3390/su8070621.

Appendix A

A.1. Vineyard phase survey

Nome azienda:	
Nome intervistato/a:	
Ruolo dell'intervistato/a	
Modalità dell'intervista	

Obiettivo della tesi: analisi degli impatti ambientali lungo la value chain del vino e determinazione dei punti critici: Il caso delle value chain del vino italiane

Obiettivo dell'intervista: trovare possibili alterative per mitigare gli impatti ambientali (in particolare water e carbon footprint) nelle fasi più critiche di questa value chain ed eventuali limiti e driver di esse.

- Chiedo gentilmente il suo consenso per registrare e utilizzare i dati raccolti tramite questa intervista ai fini della mia tesi
- Di cosa si occupa la sua azienda e quali sono le principali attività di essa?

Water footprint:

- La componente verde relativa alla water footprint viene evidenziata dagli studi analizzati come quella più critica per il consumo di acqua nella fase di vigna. Come si possono quindi ridurre le perdite per evapotraspirazione per migliorare la sostenibilità del ciclo produttivo?
- Quali sono i principali problemi o limiti legati alle possibili azioni volte a mitigare l'evapotraspirazione?

Appendix B

B.1. Packaging alternatives survey

Nome azienda:	
Nome intervistato/a:	
Ruolo dell'intervistato/a	
Modalità dell'intervista	

Obiettivo della tesi: analisi degli impatti ambientali lungo la value chain del vino e determinazione dei punti critici: Il caso delle value chain del vino italiane.

Obiettivo dell'intervista: trovare possibili alternative per mitigare gli impatti ambientali (in particolare water e carbon footprint) nelle fasi più critiche di questa value chain ed eventuali limiti e driver di esse.

- Chiedo gentilmente il suo consenso per registrare e utilizzare i dati raccolti tramite questa intervista ai fini della mia tesi
- Di cosa si occupa la sua azienda e quali sono le principali attività di essa?

Carbon footprint:

- Quali possono essere packaging alternativi alla classica bottiglia di vetro da 0.75 litri?
- Quali sono i problemi/barriere o limitazioni nell'implementazione di packaging alternativi?

Quali sono i driver legati alle attività volte a mitigare le emissioni di CO₂ equivalente derivate dalla produzione di bottiglie di vetro?

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“I guess we’ll never know”.

