UNIVERSIDAD POLITÉCNICA DE MADRID
Escuela Técnica Superior de Ingeniería
Agronómica, Alimentaria y de Biosistemas

USE OF FOOD SAFETY AND ENVIRONMENTAL MANAGEMENT TOOLS FOR THE TRANSITION TOWARDS SUSTAINABILITY IN THE WINE INDUSTRY

DOCTORAL THESIS

Submitted for the degree of Doctor by:

Jesús López Santiago
Agriculture Engineer, MSc (Agr)

Madrid, 2024

UNIVERSIDAD POLITÉCNICA DE MADRID
Escuela Técnica Superior de Ingeniería
Agronómica, Alimentaria y de Biosistemas

Doctoral Degree in Agroengineering

USE OF FOOD SAFETY AND ENVIRONMENTAL MANAGEMENT TOOLS FOR THE TRANSITION TOWARDS SUSTAINABILITY IN THE WINE INDUSTRY

DOCTORAL THESIS

Submitted for the degree of Doctor by:

Jesús López Santiago
Agriculture Engineer, MSc (Agr)

Under the supervision of:
Dr. María Teresa Gómez Villarino (UPM)

Madrid, 2024

Title: USE OF FOOD SAFETY AND ENVIRONMENTAL MANAGEMENT TOOLS FOR THE TRANSITION TOWARDS SUSTAINABILITY IN THE WINE INDUSTRY

Author: Jesús López Santiago

Doctoral Programme: Agroengineering

Thesis Supervision:

Dr. Maria Teresa Gómez Villarino (Supervisor)

External Reviewers:

Dr.

Dr.

Thesis Defence Committee:

Dr.

Dr.

Dr.

Dr.

Dr.

Thesis Defense Date:

"Caminante no hay camino,

se hace camino al andar"

Antonio Machado (1875-1939)

Dedicado a mis padres,

Jesús y Marisol

Acknowledgement

The completion of this thesis and the research work it required would not have been possible without the people to whom I want to express my gratitude:

Primarily, to my thesis supervisor, Maria Teresa, for her guidance, trust, and personal support throughout these three years. I appreciate her guidance during the thesis completion, especially for her elevated expectations and encouragement from beginning to end.

To the professors of the Agroforestry Engineering Department's Projects Area, Ana Isabel, Julia, and David, who, along with Maria Teresa, have encouraged me to complete this thesis.

To Amin, Hazaria, and Amelia for their generosity and hospitality during my stays at the Malaysian Institute of Chemical and Bioengineering Technology (Universiti of Kuala Lumpur) in Malaysia, and for their crucial support in the success of the research I conducted during that period.

To Professor Domingo Gómez Orea, who sparked my interest in research and whom I have always kept in mind to persevere until the end.

To my colleagues and friends at the company, especially Matilde, Laura, Hector, and Jose Antonio, who help me balance university work with daily business management.

Lastly, I want to express my deepest gratitude to my family, who are my motivation in life and work.

To my parents and parents-in-law, Jesús, Marisol, Antonio, and Nati, my sister, Raquel, my brothers-in-law, Mónica, David, and Alfonso, and my nieces and nephews, Hugo, and Erika, because I have always had their unconditional support.

And of course, to my wife, Gema, for her patience and understanding, which make everyday life much more bearable. And finally, to Adriana, my daughter, who gives meaning to everything I do in this life.

Abstract

This thesis investigates the integral roles of Food Safety and Environmental Management within the wine industry's sustainability framework in the context of the European Commission's Farm to Fork Strategy, part of the ambitious European Green Deal. With the global imperative for sustainable agriculture intensifying, the wine sector presents a unique case for embedding eco-friendly practices that not only ensure its longevity but also foster environmental awareness. Through rigorous empirical analysis, this research unveils a high adoption rate of Hazard Analysis and Critical Control Points systems alongside Environmental Management Systems within wineries, marking a significant shift towards sustainable operations. However, it also exposes a critical need for an enhanced focus on food safety performance and environmental management by wineries to advance towards sustainability in wine production. By proposing a “sustainability matrix” as a quantitative evaluation tool, this work illuminates the performance of wineries with respect to Food Safety and Environmental Management standards, highlighting the need for their integrated application with other components linked to its value chain aimed at achieving an improvement in the overall sustainability of the wine sector. The findings advocate for a unified approach to Food Safety and Environmental Management practices, highlighting their indispensability in achieving broader sustainability goals. Offering actionable insights, this thesis serves as a valuable resource for policymakers, industry stakeholders, and scholars dedicated to advancing environmental resilience and sustainability in agricultural practices, particularly within the viticulture domain.

Resumen

Esta tesis investiga los roles integrales de la Seguridad Alimentaria y la Gestión Ambiental dentro del marco de sostenibilidad de la industria vinícola en el contexto de la Estrategia “De la Granja a la Mesa” de la Comisión Europea, como parte del ambicioso Pacto Verde Europeo. Con el imperativo global para la agricultura sostenible intensificándose, el sector del vino presenta un caso único para la incorporación de prácticas ecológicas que no solo aseguran su longevidad, sino que también fomentan el compromiso ambiental. A través de un análisis empírico riguroso, esta investigación revela una alta tasa de adopción de sistemas de Análisis de Peligros y Puntos Críticos de Control junto con Sistemas de Gestión Ambiental dentro de las bodegas, marcando un cambio significativo hacia operaciones sostenibles. Sin embargo, también expone una necesidad crítica de un enfoque mejorado en el desempeño de la seguridad alimentaria y la gestión ambiental por parte de las bodegas para avanzar hacia la sostenibilidad en la producción de vino. Al proponer una “matriz de sostenibilidad” como herramienta de evaluación cuantitativa, este trabajo arroja luz sobre el rendimiento de las bodegas respecto a los estándares de Seguridad Alimentaria y Gestión Ambiental, subrayando la necesidad de su aplicación integrada con otros componentes vinculados a su cadena de valor dirigida a conseguir una mejora de la sostenibilidad global del sector vitivinícola. Los hallazgos abogan por un enfoque unificado de prácticas de Seguridad Alimentaria y Gestión Ambiental, resaltando su indispensabilidad para alcanzar objetivos de sostenibilidad más amplios. Ofreciendo información práctica, esta tesis sirve como un recurso valioso para formuladores de políticas, partes interesadas de la industria y académicos dedicados a avanzar en la resiliencia ambiental y la sostenibilidad en prácticas agrícolas, particularmente dentro del dominio de la viticultura.

Table of Contents

Acknowledgement iii

Abstract iv

Resumen v

Table of Contents vi

List of Figures ix

List of Tables x

Abbreviations and acronyms xi

1 Introduction 1

1.1 Origin of this thesis 1

1.2 The Food Safety and Environmental Management general concepts 3

1.3 A wine sector overview 4

1.4 How the wine is made: The winemaking process 6

1.5 Outline of the thesis 9

1.5.1 Theoretical framework, general structure, and internal alignment 11

1.5.1.1 Article overview (quality indicators) 13

1.5.1.2 FS practical application towards sustainable practices in wineries 13

1.5.1.3 EM practical application towards sustainable practices in wineries 15

1.5.1.4 Synthesis and construction of the sustainability tool based on FS and EM 16

2 State of the Art 17

2.1 Literature Review 17

2.1.1 Literature Review Methodology 17

2.1.2 The sustainability framework in the EU Agriculture Sector 22

2.1.3 Agrifood industry sustainability 30

2.1.4 Wine industry sustainability 33

2.2 Food safety management 37

2.2.1 Critical Control Points 38

2.2.2 Hazard Analysis Critical Control Point and Prerequisite Programs 39

2.2.3 FS management in wine production 42

2.3 Environmental management 46

2.3.1 EM in wine production 47

2.3.2 EM through standard ISO 14001:2015 48

2.4 Prior research 53

2.4.1 Strategic Adoption and Sector-Wide Challenges 53

2.4.2 Competitive dynamics and adoption barriers ... 58
2.4.3 EMS as a catalyst for sustainability practices ... 58
2.4.4 Enhancing sustainability through performance measurement ... 58
2.4.5 Integrating FS and sustainable practices ... 58
2.5 Research Questions, Hypothesis and Objectives ... 60
2.5.1 Research Questions (RQs) emerging from the Literature Review ... 60
2.5.2 Hypothesis ... 60
2.5.3 Objectives ... 61
3 Methods ... 62
3.1 Thesis Methodology ... 62
3.1.1 Literature Review ... 62
3.1.2 Defining the Problem Statement, Hypothesis, and Objectives ... 63
3.1.3 Method ... 63
3.1.4 Case Studies ... 63
3.1.5 Wineries performance assessment tool ... 64
3.2 Method used to establish the research case studies. ... 64
3.2.1 First Step: Evaluation of FS performance in wineries as a component towards sustainability in wine production. ... 65
3.2.2 Second Step: Establishment of FS performance indicators by evaluating the key wineries performance components in their CCPs control. ... 66
3.2.3 Third Step: Evaluation of EM performance in wineries and establishment of performance indicators by evaluating their EMS based on ISO 14001:2015. ... 67
3.2.4 Fourth Step: Wineries performance assessment tool: Sustainability Matrix ... 68
4 Results ... 71
4.1 Article one ... 71
4.2 Article two ... 90
4.3 Conference Paper ... 108
4.4 Article three ... 115
4.5 Article four ... 157
4.6 Summary scheme of the Results ... 177
4.7 Key Takeaways ... 179
5 Discussion ... 181
5.1 Interconnections between FS and EM ... 181
5.1.1 Performance variability by winery size ... 182
5.1.2 Performance in environmentally sustainable objectives ... 183
5.2 Deep dive into Training, Leadership, and Legislative Compliance ... 184
5.2.1 Training ... 184
5.2.2 Leadership role ... 186
5.2.3 Compliance challenges across winery sizes ... 187
5.3 Beyond traditional metrics about sustainable practices in wineries ... 188
5.3.1 Application of the SM in Policy Design ... 189

5.4 Limitation and strength of the thesis 190
6 Conclusion 191
7 Future research 197
References 199
Annexes 205

List of Figures

Figure 1. Explanatory figure on the development of research from the study of performance in FSMS and EMS in wineries……10

Figure 2. Canvas approaching and the aspects developed in thesis research compendia……13

Figure 3. Flow diagram of the PRISMA methodology at four levels applied to the literature review……17

Figure 4. Clusters identified from WoS Core Collection data from the period 2012–2022 using search QUERY: (ALL=(WINE*)) AND ALL=(SUSTAINABILITY). ……20

Figure 5. Decision canvas to identify CCPs……39

Figure 6. Flow diagram of the young wine making process and corresponding CCPs to each stage of this process ……45

Figure 7. Thesis methodology……63

Figure 8. Flow diagram of the case studies process……66

List of Tables

Table 1. Relations among Chapter, objectives, results, and articles 12

Table 2. Inclusion/Exclusion criteria for literature review..21

Table 3. Main milestones in agriculture and sustainability in the past five years..24

Table 4. Key principles of HACCP 41

Table 5. Main CCPs and oPRPs in the production of young red wine 44

Table 6. Main requirements of the 14001:2015 standard 50

Table 7. Comparative analysis of prior research 54

Table 8: Sustainability Matrix based on the performance of the FSMS and EMS..158

Table 9. Research results .summary..176

Abbreviations and acronyms

AI	Artificial intelligence
AMR	Antimicrobial resistance
ASC	Agrifood Supply Chain
BSE	Mad cow disease
CCP	Critical control point
CCPs	Critical control points
EM	Environmental management
EMS	Environmental Management System
EC	European Commission
EU	European Union
FAO	Food and Agriculture Organization
FS	Food safety
FSMS	Food Safety management systems
F2F	Farm to Fork
GFSI	Global Food Safety Initiative
GMP	Good Manufactural Practices
HACCP	Hazard Analysis Critical Control Point
IoT	Internet of Things
ISO	International Organization for Standardization
KPI	Key Performance Indicator
M2M	Machine to Machine
NACMF	National Advisory Committee on Microbiological Criteria for Foods
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
OIV	Organisation Internationale de la Vigne et du Vin
SO	Specific Objective
OTA	Ochratoxin A
PDO	Protected Designation of Origin
PRPs	Prerequisite programs

PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analysis
SDGs	Sustainable Development Goals
SWNZ	Sustainable Winegrowing New Zealand
UniKL-MICET	Universiti of Kuala Lumpur – Malaysian Institute of Chemical and Bioengineering Technology.
WSC	Wine supply chain
WVC	Wine value chain
WoS	Web of Science

1 Introduction

1.1 Origin of this thesis

In the face of mounting environmental and social challenges, the sustainability of agrifood production has emerged as a pressing global priority (McGreevy et al., 2022). Despite significant strides in reducing the sector's environmental impact—evidenced by a 20% reduction in greenhouse gas emissions and a 17.7% decrease in nitrates in rivers since 1990 (European Commission, 2019a), the agrifood industry continues to grapple with inefficiencies and unsustainable practices. Notably, 20% of food produced in the European Union goes to waste, highlighting the urgent need for comprehensive reform (European Commission, 2019a). This research focuses on the indispensable roles of Food Safety (FS) and Environmental Management (EM) within the Agrifood Supply Chain (ASC), underpinned by the European Commission's Farm to Fork (F2F) Strategy. Through this lens, the research advocates for a comprehensive approach to achieving a sustainable, resilient, and environmentally friendly food system.

Agrifood production continues to exert substantial pressure on natural resources and ecosystems, underscoring the imperative for sustainable transformation. Numerous studies illustrate instances of environmental harm or foodborne illnesses attributable to inadequate agro-industrial practices, overuse of chemicals and the contamination of food and ecosystems that represent significant health risks and environmental challenges (Bisht & Chauhan, 2020; Dhuldhaj, Singh, & Singh, 2023; Gallo, Ferrara, Calogero, Montesano, & Naviglio, 2020; Hou et al., 2020; Jallow, Xie, Tang, Qi, & Li, 2021; Munishi, Ndakidemi, Blake, Comber, & Hutchinson, 2021; Rajkovic et al., 2020; Sarker et al., 2022; Srivastav, 2020; Todd, 2020). These issues are compounded by inefficiencies leading to substantial food waste, further exacerbating the environmental footprint of food production.

The growing attention to the need for change in agrifood industry is reflected in the 2030 Agenda for Sustainable Development and in its Sustainable Development Goals (SDGs) (Bartolucci et al., 2020; Griggs et al., 2014). Specifically, Sustainable Development Goal 9 "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation" and its Target 9.4 address to upgrade all industries and infrastructures for sustainability (United Nations, 2015). Major transformations are needed to promote sustainability, to avoid food waste, and generate a change towards healthy nutrition and safeguarding human health (Fischer & Miglietta, 2020). It is mandatory to propose forms of food production that are compatible with the conservation of the environment, that is, agro-industrial production methods that generate less degradation of ecosystems and natural resources, while guaranteeing food security and healthy nutrition for consumers (Dobermann, Swift, & Field, 2013).

The European Commission's Farm to Fork (F2F), a key component of the European Green Deal, signifies a comprehensive commitment to reforming the food system. Prioritizing sustainability, this strategy encompasses a broad spectrum of initiatives aimed at reducing environmental impact, promoting biodiversity, and ensuring food safety throughout the supply chain (European Commission, 2019b). F2F Strategy specifically focuses on the food system, aiming to make it more sustainable, resilient, and environmentally friendly. F2F Strategy prioritizes sustainability in agriculture, emphasizing environmentally conscious practices, biodiversity preservation, and climate change mitigation. It also aims to ensure high food safety standards across the food supply chain, reduce the use of chemical pesticides and fertilizers, promote the transition to organic farming, and encourage a circular economy in the food sector, thereby minimizing waste and optimizing resource utilization (Billen et al., 2024; Schebesta, Bernaz, & Macchi, 2020).

The effective integration of FS and EM within the Agrifood Supply Chain (ASC) is fundamental to achieving sustainable outcomes as ensuring consumer health and reducing environmental impact aligned with the F2F. Despite notable advancements, the concurrent achievement of FS and EM objectives remains a challenge, highlighting a **significant knowledge gap** in practical their implementation strategies within the agrifood industry. Certain shortcomings are evident concerning the practical application of FS and EM in the industry's food production processes, the essential components required for optimal FS and EM performance, and the industry's strengths and vulnerabilities in utilizing tools designed to secure satisfactory FS and EM outcomes.

FS and EM are essential elements that contribute to one of the five components of the ASC sustainability. According to Aramyan (2007), sustainability arises from four dimensions of ASC Performance (Aramyan, Oude Lansink, van der Vorst, & van Kooten, 2007). This chain encompasses all activities involved in agricultural food handling, from producers and farmers to customers (Mangla et al., 2018). Aramyan identified four primary categories of performance dimensions: efficiency, flexibility, responsiveness, and food quality. Additionally, a category was introduced to encompass a wide range of complementary critical aspects reflecting the social and environmental dimensions of sustainability (Varsei, Soosay, Fahimnia, & Sarkis, 2014). Gold (2017) further specified the sustainability dimension by incorporating indicators such as local living conditions, labour rights, land rights, FS, end-of-life valorisation through biomass recycling, and environmental issues (Gold, Kunz, & Reiner, 2017).

The wine industry serves as a pertinent example of the broader ASC, embodying both the challenges and opportunities associated with sustainable production. Wine production, a significant sector within agrifood, faces unique sustainability challenges, including water use, chemical management, and biodiversity conservation. Simultaneously, it presents opportunities for innovation and sustainable practice implementation, particularly in areas such as organic viticulture and waste management. From the consumers viewpoint, credibility and transparency regarding sustainable practices are increasingly influencing purchasing decisions (Gold, Kunz, & Reiner, 2017). This is particularly evident in the wine industry, where consumers are showing a preference for products that demonstrate a commitment to environmental stewardship and social responsibility.

1.2 The Food Safety and Environmental Management general concepts

FS occurs when people have permanent access to enough amounts of safe and nutritious food to sustaining life and promoting good health (Käferstein & Abdussalam, 1999; Regional Committee for the Eastern Mediterranean, 1999). This concept has been growing in importance over the last decades, extending not only to food but also to all links in the food chain, from primary production through the processes of transformation, manufacturing, handling, and packaging to sale to consumers and the preparation of food by the final consumer. Hazard Analysis Critical Control Point (HACCP) method is widely recognized internationally, and it is a systematic approach to FS Management Systems (FSMS). It aims to establish effective FS practices through compliance with its principles, which consist of seven steps designed to identify and manage FS hazards (Mortimore &

Wallace, 2013). Furthermore, HACCP requires the implementation of appropriate corrective measures when necessary and the availability of a documentation system for record-keeping purposes (Gehring & Kirkpatrick, 2020).

EM is defined as a multi-layered process associated with the interaction of state and non-state environmental managers with the environment and with each other. Environmental managers are those whose livelihood is primarily dependent on the application of skill in the active and self-conscious, direct, or indirect, manipulation of the environment with the aim of enhancing predictability in a context of social and environmental uncertainty (Geoff A. Wilson & Raymond L. Bryant, 1997). EMS refers to a set of procedures, rules, and evidence-based practices that organizations establish to mitigate the environmental impacts associated with their activities (Barla, 2007). This approach is widely adopted by many companies globally (Marimon, Llach, & Bernardo, 2011; Neves, Salgado, & Beijo, 2017). International Organization for Standardization (ISO) 14001:2015 standard is often used as the basis for EMS implementation, serving as a proactive EM tool (Summers Raines, 2002). By adopting EMS, organizations can effectively manage their environmental impacts and enhance their environmental performance.

1.3 A wine sector overview

The wine sector exhibits extensive variety and a significant presence on the global stage. Dramatic shifts have taken place over the last five decades in vineyard coverage, the economic value of production, and patterns in market demand and consumer behaviour International Organisation of Vine and Wine, 2021; Pomarici, 2016). Internationally, upwards of 40% of all wine consumed is sourced from international imports (Anderson, Nelgen, & Pinilla, 2017), with the European Union dominating as the foremost exporter, responsible for 70% of global wine exports (International Organisation of Vine and Wine, 2021).

The worldwide expanse dedicated to vine cultivation stood at 7.3 million hectares in 2020, which includes areas allocated for the making of wine and juices, cultivation of table grapes and raisins, and immature vineyards awaiting their first production cycle (International Organisation of Vine and Wine, 2021). Wine grape cultivation accounts for about 55% of this total land use. In the same year, the total wine output reached 260 million hectolitres, with Italy, Spain, France, and the United States leading as the major wine-producing countries (International Organisation of Vine and Wine, 2021).

In the late 1970s, the global expanse of vineyards reached a pinnacle, averaging 10.2 million hectares from 1975 to 1980 (Anderson et al., 2017). This era of expansion was followed by a notable decrease in vineyard areas, particularly in the "Old World" wine countries such as France, Spain, Italy, and Portugal, leading to a shift in the global landscape. By the 1980s, Europe accounted for 70% of the worldwide vineyard area, but this proportion dropped to around 50% by 2019 (Anderson et al., 2017). This change was partly due to EU policies between 2008 and 2011 aimed at reducing wine surplus, alongside growth in vineyard areas in countries like Chile, Australia, South Africa, New Zealand, and China. This period also saw a dynamic expansion in the international wine market, with trade volume increasing by about 80% and trade value doubling from 2000 to 2020.

As the global market evolved, traditional wine-producing nations experienced a decline in market share, challenged by New World countries that have been scaling up their production, improving quality, and refining their branding. Countries such as Chile and New Zealand have notably enhanced their competitive edge, demonstrating a keen ability to respond to market needs (Anderson et al., 2017; Organisation Internationale de la Vigne et du Vin, 2022; Pomarici, 2016). The financial crisis of 2008 led to a stabilization in global wine consumption, which has hovered between 240–245 million hectolitres since 2009, albeit with a minor drop to 234 million hectolitres in 2020, marking a 3% reduction from the previous year (International Organisation of Vine and Wine, 2021). Despite these changes, the United States has continued to lead as the primary wine consumer globally, with 33 million hectolitres in 2020, surpassing France (24.7 million hL) and Italy (24.5 million hL) (International Organisation of Vine and Wine, 2021).

The 2022 global wine production, despite a heatwave affecting various regions, was like the previous year's, marking the fourth consecutive year of slightly below-average production. In the EU, balanced outputs from Italy, France, and Germany offset lower yields in Spain and Greece, affected by summer heatwaves. The USA expected a minor decrease in production from 2021. Notably, New Zealand achieved its largest production ever due to favourable climatic conditions. Overall, global wine production was slightly below its 20-year average, with early harvests and average volumes reported, yet good quality expected (Organisation Internationale de la Vigne et du Vin, 2022).

Expanding on the wine domain, the industry not only caters to traditional wine enthusiasts but also explores innovative blends and organic wine varieties, catering to a growing segment of health-conscious consumers. The evolution of wine tourism has added another dimension to the industry, inviting enthusiasts to experience vineyards and wineries firsthand, further enriching the global wine culture. Moreover, the advent of technology in viticulture and enology has introduced sophisticated methods of production and preservation, enhancing both the quality and sustainability of wine production. Wine production is an integral food chain part and, as such, is closely related to the sustainability of the food chain.

In the EU, wine sector contributed €130 billion to the EU's GDP in 2022, accounting for 0.8% of the total GDP, with wine exports valued at €17.9 billion, demonstrating the sector's substantial role in international trade and its contribution to reducing the EU's trade deficit. Employment within the sector was notable, generating 2.9 million jobs, which is about 1.4% of EU employment, indicating an elevated level of productivity and added value per employee. The wine industry's commitment to research and development was evident with an investment of over €1.1 billion, funding projects across viniculture, sustainability, and product innovation, among others, which accounted for 0.3% of the total EU R&D investment. Fiscal contributions from the sector were nearly €52 billion in 2022, underlining its significance in supporting public finances through social contributions and personal income tax (Comité Européen des Entreprises Vins, – CEEV, 2024).

1.4 How the wine is made: The winemaking process

Wine production involves the grapes cultivation, the transformation of grapes into wine, and the distribution and commercialization of the final product (Robertson, 2006). Overall, the production of wine is a crucial component of the food chain, and its sustainability is paramount to ensure the long-term viability of the food system. By recognizing the impact of each stage of wine production on the sustainability of the food chain and implementing appropriate measures, we can promote responsible wine production and consumption and contribute to a more sustainable future.

Vineyards cultivation can be a significant source of negative environmental impacts. Use of pesticides and chemical fertilizers in vineyard agriculture can impact the quality of soil and water, which in turn can affect human health and the local ecosystem (Andersson & Nilsson, 1972; Yang et al., 2022). The presence of these contaminants in the wine itself can pose a risk to consumers (Chen, C. et al., 1997; Flora, Flora, & Saxena, 2006). Therefore, it is vital to monitor the entire wine production process carefully and ensure that all materials used meet strict safety standards. Additionally, wine production may require substantial amounts of water, which can be problematic in regions where water is scarce (Fraga, Malheiro, Moutinho-Pereira, & Santos, 2012).

The transformation of grapes into wine can also have a significant environmental impact. Fermentation and aging processes may require copious amounts of energy, which can contribute to greenhouse gas emissions (Colman & Päster, 2009). Additionally, wine production generates liquid and solid waste that can contaminate the environment if not properly managed (Kosseva, 2017). These waste products such as grape skins and stems, which can potentially harbour harmful bacteria and other contaminants that could contaminate the wine as a product and affect consumer´s health. Grapes, must, and wines are susceptible to several safety hazards. These FS risks include physical (metal parts, glass, insects), chemical (pesticide residues, heavy metal residues, urea), and microbiological (pathogens) hazards affecting the health of consumers (Christaki & Tzia, 2002). Hazards that appear in wine production may come from the environment, processing equipment, and workers of the winery. Nevertheless, the two common causes of major FS incidents are those related to undeclared allergens and cross-contamination (Lee, J. C. et al., 2021). Hygienic conditions and practices are required to prevent the introduction of hazardous agents.

Distribution and commercialization of wine can also have significant impacts on the sustainability of the food chain. Transport and storage of wine can generate greenhouse gas emissions, and glass packaging can have an impact on the environment if not properly recycled (Point, Tyedmers, & Naugler, 2012).

The winemaking process follows appropriate steps along with the addition of certain additives, such as sulphur dioxide, tartaric acid, or egg albumin (Robertson, 2006). The wines are manufactured using a common generic process but with some variations depending on the type of wine that is being produced. In the European Union, these oenological practices are regulated by European Commission (EC) Regulations n° 423/2008, n° 479/2008, and n° 606/2009 (European Commission, (2008), 2008; European Commission, (2009), 2009; European Council, 2008).

The process of making red wine begins when grapes are harvested and transported to the winery. Grapes are crushed and stemmed, obtaining a semi-liquid composed of skins, seeds, pulp, musts, and scrapes. Subsequently, it receives corrections such as the addition of sulphur dioxide to obtain an antioxidant and an antiseptic effect. All these additives are regulated in the EU by EC Regulations n° 1333/2008, n° 1129/2011, and n° 1130/2011 (European Commission, (2011), 2011a; European Commission, (2011), 2011b ; European Parliament & European Council, 2008).

Large vats are where alcoholic fermentation occurs as yeasts trigger the conversion of sugars into ethanol (Miller & Block, 2020). Simultaneously, maceration and fermentation processes take place (Casassa & Harbertson, 2014; Setford, Jeffery, Grbin, & Muhlack, 2017). The liquid part of the grape, referred to as must-wine, undergoes transformation during the fermentation process while also exchanging components with the solid parts of the grapes. Extraction of anthocyanins from the skins is crucial as they provide the final red colour of wines (He et al., 2012; Metivier, Francis, & Clydesdale, 1980; Romero-Cascales, Fernández-Fernández, López-Roca, & Gómez-Plaza, 2005). The duration of alcoholic fermentation depends on the temperature, ranging from 10 to 20 days (Sablayrolles, 2009).

The drawing off of the vat signals the onset of malolactic fermentation, where lactic bacteria transform malic acid into lactic acid (Davis, Wibowo, Eschenbruch, Lee, & Fleet, 1985). This process stabilizes the wine, impeding the growth of harmful bacteria (Lonvaud-Funel, 1999). Any particles present, such as yeasts, solids, or organic matter, settle and accumulate at the bottom of the vat, collectively termed as "wine waste".

Racking is employed to avoid any contact between the wine and the "wine waste," which could compromise the wine's organoleptic properties. Clarifying or colloidal substances, such as egg albumin, gelatine, or alginate, are added to eliminate suspended particles (Mierczynska-Vasilev & Smith, 2015; Oliva, Payá, Cámara, & Barba, 2007; Vernhet, 2019). Then, the wine is filtered through a porous material to retain possible solid particles that remain in the liquid phase eliminating turbid or precipitated wines (McRae et al., 2017).

In the next step, the wine is stabilized chemically and biologically by cold keeping wine stable in the long term (Vernhet, 2019). This stage inhibits microbial growth, and it avoids oxidative reactions.

Finally, the wine is bottled to protect it from external agents that deteriorate it.

1.5 Outline of the thesis

The thesis is composed by nine chapters. Chapter One contains the preliminary considerations of the thesis and includes a general overview and the outline of the thesis. Chapter Two is the Introduction that encompasses a comprehensive review of the relevant literature and a detailed description of the research tools employed, the hypothesis and the objectives. In this chapter, it has been reviewed relevant literature on FS and EM within the ASC and WSC. The focus is on identifying and applying these insights to enhance sustainability in wine production. This review has been structured according to the logical framework outlined in **Figure 1**, and it has generated seven research questions related to use FS and EM for the transition towards sustainability in the wine industry, which have been identified as one general objective and six specific objectives of the thesis. To address these research objectives, PRPs, HACCP and ISO 14001:2015 methodologies have been analysed for their application in wine production, as they are commonly utilized in the industry.

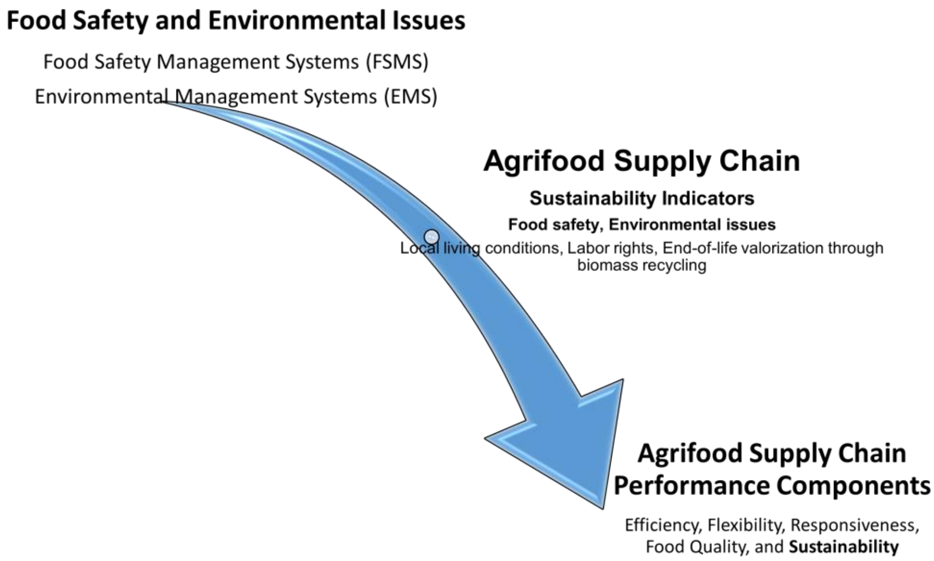

Figure 1. Explanatory figure on the development of research from the study of performance in FSMS and EMS in wineries.

The next three Chapters represents the central focus of the thesis. They contend the methods (Chapter Three), the results (Chapter Four) and the discussion (Chapter Five). Three research case studies were analysed regarding to the sustainability in the wine industry from the perspectives of FS and EM. This part outlines the main findings from the analysis and serves as the basis for the materials and methodologies used in the research. The first study systematically analyses the performance of "Vinos de Madrid" Protected Designation of Origin (PDO) in the implementation of FSMS, with a focus on the implementation of PRPs and the HACCP system tools. The second study develops a survey-based methodology to evaluate the performance of CCPs in Spanish wineries to define the indicators and components for analysing sustainability based on FS in the wine industry. The third study examines the performance of wineries in Italy regarding the implementation of EMS using a survey-based methodology, and subsequently, establishes the indicators and components for analysing sustainability based on EMS in the wine industry. Research studies have been published as scientific articles in three prestigious journals and all research related to sustainability based on FSMS were also presented at an international agroengineering congress. Chapter Three outlines the main findings from this analysis and serves as the basis for the methodologies used in the research.

Chapters Six and Chapter Seven comprises the primary conclusions and future research directions that have resulted from the overall research presented in second part. This part provides a summary of the research findings and conclusions. It is divided into two main sections: conclusions and findings on sustainability in wine production with respect to the research objectives (Chapter Six), and general remarks and future research directions (Chapter Seven). The former chapter highlights the key research outcomes, while the latter chapter offers insights for future research and identifies areas that require further investigation.

Chapter Eight includes four annexes. Annex A is a comprehensive summary of the prior research that has been analysed at the Chapter One and Annexes B, C and D include the three questionnaires that have been utilized in the three studies, respectively.

Chapter nine contents the References.

1.5.1 Theoretical framework, general structure, and internal alignment

Table 1 has been prepared to provide a concise outline that identifies the structure of the thesis, the theoretical framework, and the relationship among the research questions, objectives, results, and the included articles. **Table 1** serves as a concise outline that effectively delineates the structural components of the thesis, providing clear insights into the theoretical framework employed throughout the research. Moreover, it elucidates the intricate relationships among the research questions, objectives, results, and the articles included within the study. This organized presentation aids in navigating the complex interactions and ensures a coherent flow of information.

This thesis is the result of three years of work developed in the international framework together with researchers from the Malaysian Institute of Chemical and Bioengineering Technology of the Universiti of Kuala Lumpur (UniKL-MICET). This circumstance has influenced the definition of methodological tools and has also allowed their international character. It has established a framework of continuous collaboration between both universities, giving a vision of Southern Europe and Southeast Asia.

Table 1. Relation among theoretical framework, general structure, the research questions and objectives, articles, and research methods.

G.O.	SPECIFIC OBJETIVES	THEORETICAL FRAMEWORK RESEARCH QUESTIONS	ARTICLES	RESEARCH METHODS
General Objective Propose a measure of the progress towards sustainability in wineries based on specific management tools		CONCEPTUALIZATION Definition and positioning of concept of FS and EM as a tool to evaluate the sustainable practices in wine production. RQ.01.-	Comprehensive review	Systematic literature review using PRISMA.
	SO-1.- Analyse and evaluate the FS management in promoting the sustainability of the WINE PRODUCTION.	IMPLEMENTATION Description of FS practical application in two wineries groups and identification of gaps, FS main components performance and method for using FS as tool for metric sustainable practices in wine production RQ.01, RQ.02	Article One	Case Study One
	SO-3.- Identify and analyse key components of sustainability in the wineries based on FS management and EM.		Article Two	Case Study Two.
	SO-2.- Analyse and evaluate the EM performance in promoting the sustainability of the WINE PRODUCTION.	IMPLEMENTATION Description of EM practical application in a wineries group and identification of gaps, EM main components performance and method for using EM as tool for metric sustainable practices in wine production. RQ.01, RQ.03	Article Three	Case Study Three.
	SO-3.- Identify and analyse key components of sustainability in the wineries based on FS management and EM.			Case Study Three.
	SO-4.- Design a tool to measure progress of sustainability and test it.	IMPLEMENTATION Synthesis and construction of the tool based on FS and EM performance indicators to measure progress towards sustainability in wine production. RQ.04	Article Four.	
		PRESENTATION OF THE FINDINGS		Results and Discussion
		CONCLUSIONS/ FUTURE RESEARCH		

1.5.1.1 Article overview (quality indicators)

Figure 2 presents the general approach and the specific elements addressed in the research compendia. It illustrates how each component contributes to the overarching research objectives, offering a clear visualization of their integral roles within the comprehensive research framework.

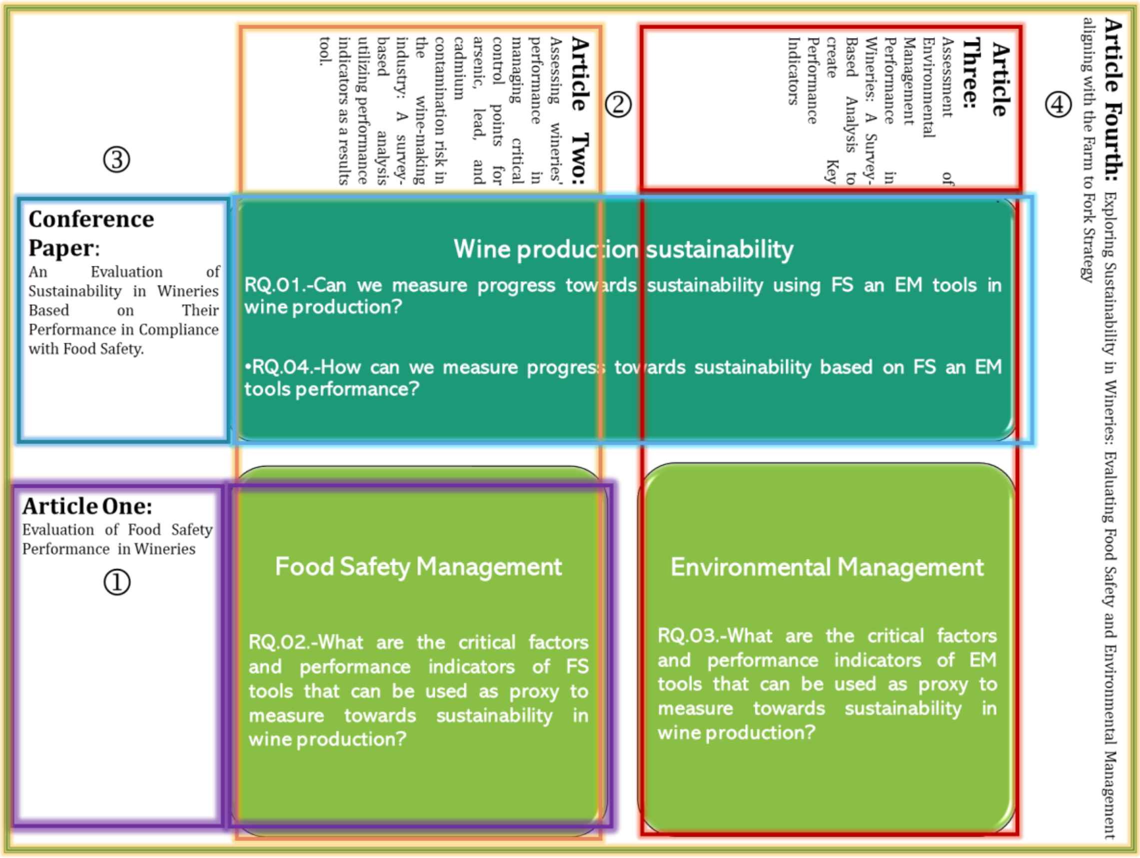

Figure 2. Canvas approaching and the aspects developed in thesis research compendia.

1.5.1.2 FS practical application towards sustainable practices in wineries

Description of FS practical application in two wineries groups and identification of gaps, FS main components performance and method for using FS as tool for metric sustainable practices in wine production.

- López-Santiago, J., García, A. I. G., & Gómez-Villarino, M. T. (2022). **An Evaluation of Food Safety Performance in Wineries.** Foods, 11(9), 1249. DOI: 10.3390/foods11091249. Metrics: FOOD SCIENCE & TECHNOLOGY (SCIE). JCR YEAR 2022.

JIF RANK: 34/142. JIF QUARTILE: Q1. JIF PERCENTILE: 76.4. CITATION: 6. Published: MAY 2022. (Source: WoS)

This study presents a methodology to evaluate the performance of the FS system in wineries, focusing on the implementation of the PRPs and HACCP system. Specifically, the study analysed the performance of wineries in the Protected Denomination of Origin "Vinos de Madrid" in controlling CCPs throughout the winemaking process, including the implementation of both PRPs and HACCP principles. The research was conducted through a survey of fifty-five questions on a sample of twenty-one wineries and identified the control of metals in grapes and the control of fungicides or pesticides in harvest reception as the worst performing CCPs. The questionnaire has been incorporated into Appendix A.

- López-Santiago, J., García, A. I. G., Villarino, A. G., Som, A. M., & Gómez-Villarino, M. T. (2024). **Assessing wineries' performance in managing critical control points for arsenic, lead, and cadmium contamination risk in the wine-making industry: A survey-based analysis utilizing performance indicators as a results tool**. Heliyon, 10(1). https://doi.org/10.1016/j.heliyon.2023.e22962. Metrics: MULTIDISCIPLINARY SCIENCES (SCIE). JCR YEAR 2022. JIF RANK: 23/73. JIF QUARTILE: Q2. JIF PERCENTILE: 69.2. CITATION: 1. Published: JAN 2024. (Source: WoS)

This paper outlines a novel methodology for assessing the sustainability of wineries based on their ability to manage CCPs in their FSMS. More specifically, it focuses on the performance of the CCP related to the contamination risk posed by arsenic, cadmium, and lead, which has been identified as one of the least effectively controlled points. The methodology employed involves a sixteen-question questionnaire, coupled with the calculation of three performance indicators for the training, legislation, and analysis components of CCP management.

- **An Evaluation of Sustainability in Wineries Based on Their Performance in Compliance with Food Safety**. In Proceedings of the 12th Iberian Agroengineering Congress. XII Congreso Ibérico de Agroingeniería. (2023) Junta de Andalucía: Sevilla - Spain. ISBN: 978-84-09-53018-2

The article illustrates the second and fourth objectives by providing a comprehensive analysis of FS performance in wineries. It examines the enforcement of hygiene regulations and the utilization of the HACCP methodology, thereby assessing its application in utilizing FSMS as tools to enhance sustainability within the WINE PRODUCTION. Furthermore, the study proposes a quantitative approach that leverages the performance of FS in wineries. This approach serves as a quantitative measure of maturity and progression towards sustainability within the WINE PRODUCTION, offering a novel metric to gauge the effectiveness and impact of FS initiatives on broader sustainability goals. This conference presentation titled addresses the challenge of promoting sustainable food production methodologies within the agri-food industry. Both studies involved two main focuses, which are the use of metrics to assess sustainable practices in FS performance, specifically in reference to CCPs management in wineries. Congress presentation emphasizes the importance of using performance indicators, such as training, legislation, and physical-chemical analysis, as a means of measuring progress in implementing FS sustainability dimensions. Also, it offers a dual case study based on wine production, examining the performance of wineries in managing their FS system, which includes the identification and control of CCPs, and the risk of contamination by arsenic, cadmium, and lead during wine production.

1.5.1.3 EM practical application towards sustainable practices in wineries

Description of EM practical application in a wineries group and identification of gaps, EM main components performance and method for using EM as tool for metric sustainable practices in WINE PRODUCTION

- López-Santiago, J., García, A. I. G., Villarino, A. G., Som, A. M., & Gómez-Villarino, M. T. (2024). **Assessment of Environmental Management Performance in Wineries: A Survey-Based Analysis to create Key Performance Indicators.** Environments 2024, Metrics: ENVIRONMENTAL SCIENCES (ESCI). JCR YEAR 2022. JIF RANK: 190/334. JIF QUARTILE: Q3. JIF PERCENTILE: 43.26. (Source: WoS). CITATION: - Published: **UNDER PEER REVIEW**

This paper presents a methodology for evaluating the sustainability of wineries based on their ability to manage their EMS according to ISO 14001:2015 standards. The survey was designed with a questionnaire consisting of thirty-four questions divided into nine sections. Six dimensions were identified, including leadership, planning, support, operation, performance evaluation, and improvement. The methodology involves calculating five performance indicators for each dimension to evaluate the EM wineries' performance. The questions were based on the content of ISO 14001:2015 and research studies on environmental impacts in Italian wine production.

1.5.1.4 Synthesis and construction of the sustainability tool based on FS and EM

Synthesis and construction of the sustainability tool based on FS and EM performance indicators.

- López-Santiago, J.; Md Som, A.; Asyadi Bin Md Yusof, F.; Mazarrón, F.R.; Gómez-Villarino, M.T. **Exploring Sustainability in Wineries: Evaluating Food Safety and Environmental Management Aligning with the Farm to Fork Strategy.** Agriculture 2024, 14, 330. https://doi.org/10.3390/agriculture14030330. Metrics: AGRONOMY (SCIE). JCR YEAR 2022. JIF RANK: 17/88. JIF QUARTILE: Q1. JIF PERCENTILE: 81.3. CITATION: - Published: MAR 2024. (Source: WoS)

This paper presents a methodology for evaluating the sustainability of wineries based on their ability to manage their EMS according to ISO 14001:2015 standards. The survey was designed with a questionnaire consisting of thirty-four questions divided into nine sections. Six dimensions were identified, including leadership, planning, support, operation, performance evaluation, and improvement. The methodology involves calculating five performance indicators for each dimension to evaluate the EM wineries' performance. The questions were based on the content of ISO 14001:2015 and research studies on environmental impacts in Italian wine production.

2 State of the Art

2.1 Literature Review

2.1.1 Literature Review Methodology

The research has been diligently conducted in accordance with the guidelines set forth by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement (Moher, Liberati, Tetzlaff, Altman, & PRISMA Group*, 2009; Urrútia & Bonfill, 2013). This ensures a thorough implementation of systematic reviews as depicted in **Figure 3**. A systematic literature review was performed utilizing the PRISMA methodology. The PRISMA screening phase was conducted using bibliometric analysis facilitated by the CiteSpace software (version 6.1.R6, Chaomei Chen, Philadelphia, PA, USA). Furthermore, bibliometric analyses were applied to enhance the dependability of the outcomes and to reduce the potential subjective bias in the literature review (Qaiser, Ahmed, Sykora, Choudhary, & Simpson, 2017; Zupic & Čater, 2015).

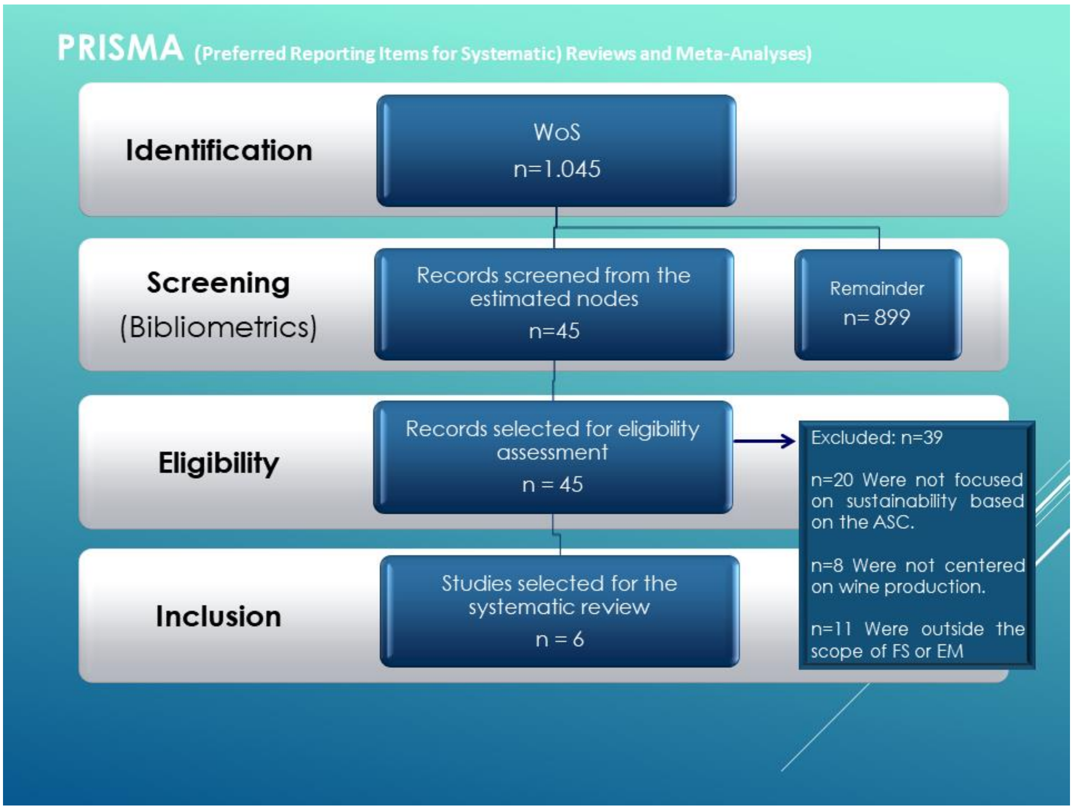

Figure 3. Flow diagram of the PRISMA methodology at four levels applied to the literature review.

To arrive at information pertinent to this study, data were retrieved in 2022 from the Web of Science (WoS) core collection platform by Clarivate analytics, which is the world's premier database for published articles and citations. It included publications in top-tier journals and is most suited for bibliometrics It included publications in top-tier journals and is most suited for bibliometrics (Korom, 2020). The search was conducted in January 2022 and data from the period 2012–2022 were analysed. The search was QUERY: (ALL=(WINE*)) AND ALL=(SUSTAINABILITY) in the WoS Core Collection. Unique records found were 1,149 documents from journals related to the query during 01-01-2012 to 01-02-2022.

Main WoS Categories were Environmental Sciences with 355 documents (30.89%), Green Sustainable Science Technology with 316 documents (30.90%), Environmental Studies with 249 documents (21.67%), Food Science Technology with 191 documents (16.62%), Business with 90 documents (7.83%), Horticulture with 87 documents (7.57%), Engineering Environmental with 86 documents (7.48%), Agronomy with 84 documents (7.31%), Management with 69 documents (6.00%); Agriculture Economics Policy with 68 documents (5.91%), Agricultural Multidisciplinary with 68 documents (5.91%); Plant Sciences with 57 documents (4.96%), Economics with 40 documents (3.48%), Biotechnology Applied Microbiology with 33 documents (2.87%), Hospitality Leisure Sport Tourism with 33 documents (2.87%), Geography with 25 documents (2.17%), Soil Science with 24 documents (2.08%), Nutrition Dietetics with 23 documents (2.00%), Regional Urban Planning with 20 documents (1.74%), Ecology with 19 documents (1.65%), Energy Fuels with 19 documents (1.65%), Agricultural Engineering with 15 documents (1.30%), Chemistry Applied with 15 documents (1.30%), Engineering Chemical with 15 documents (1.30%) and Chemistry Multidisciplinary with 14 documents (1.21%).

Document types were 1,149 divided in 899 Articles (78.24%), 154 Proceeding Papers (13.40%), 92 Review Article (8.01%), 54 Book Chapters (4.70%), 9 Editorial Materials (0.78%), 2 Early Access (0.17%), 2 Letters (0.17%), 2 Meeting Abstracts (0.17%), 1 Book (0.09%) and 1 Correction (0.09%).

About documents publication years, 44 were published in January 2022 (3.66%), 257 in year 2021 (21.38%), 227 in year 2020 (18.89%), 161 in year 2019 (13.39%), 139 in year 2018 (11.56%), 89 in year 2017 (7.40%), 101 in year 2016 (8.4%), 73 in year 2015 (6.07%) 49 in year 2014 (4.08%), 39 in year 2013 (3.24%) and 23 in year 2012 (1.91%).

Main countries of documents origin are Italy with 301 documents (25.04%), Spain with 163 documents (13.56%), USA with 160 documents (13.31%), Australia with 159 documents (13.23%), Portugal with 114 documents (9.84%), France with 77 documents (6.41%), Germany with 70 documents (5.82%), England with 47 documents (3.91%) and New Zealand with 44 documents (3.66%).

Articles were imported into CiteSpace (Chaoemi Chen. Released 2022. CitiSpace, Version 6.1.R6 for Windows 10) in plain text format, and the node type was selected as" Author", "Keywords", "References" and "Cited Author" for the bibliometric and network analyses. Time Slicing were selected from January 2012 to December 2022 and one year per slice.

Eleven clusters were found (**Figure 4**) and the ranked terms by clusters were the next:

#0: economic performance: wine industry; **environmental certified management standards**; organizational culture; business performance; environmental proactivity | wine business; business model; family business; business models; organizational change**.**

#1: finnish wine supply chain: life cycle assessment; greenhouse gas emissions; scenario analysis; **sustainable wine production**; winery wastewater | carbon footprint; performance efficiency; French wine; indicator; branded wines.

#2: sustainable wine: environmental sustainability; buying behavior; market segmentation; social media; non-market valuation | wine sector; cluster analysis; co2 emissions; renewable energy; cultural multilevel selection.

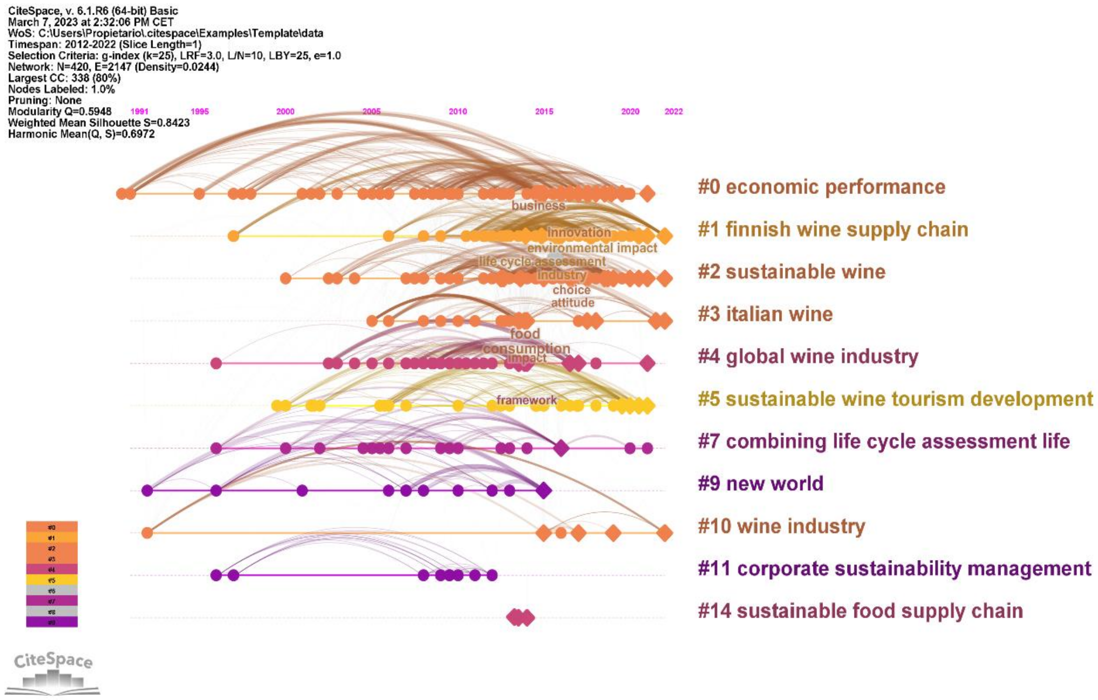

Figure 4. Clusters identified from WoS Core Collection data from the period 2012–2022 using search QUERY: (ALL=(WINE*)) AND ALL=(SUSTAINABILITY).

#3: italian wine: water footprint; informed decision-making; logistic regression model; tendone system; regression analysis | life cycle assessment; **environmental sustainability**; risks assessment; logistic regression model; tendone system

#4: global wine industry: carbon footprint; mapping techniques; resource efficiency; closed-loop supply chains; **agri-food chains** | wine industry; social impact coefficient; supply chain network design; carbon emissions; measurement systems.

#5: sustainable wine tourism development: wine tourism; industrial heritage; sustainable tourism; industrial tourism; local community | food sovereignty; rural tourism; food tourism; transformative tourism; wine business

#7: combining life cycle assessment life: vineyard sustainability; carbon footprint; monte carlo simulation; water footprint; sustainable packaging | sustainable packaging; **environmental impact**; materials reduction; vikor technique; wine-growing systems.

#9: new world: concept map; mixed methods; focus group method; nominal group technique | nominal group technique; focus group method; concept map; mixed methods.

#10: wine industry: sustainable development; occupational safety; balearic islands; values chain; organic farming adoption | carbon footprint; closed-loop supply chains; supply chain; food industry; life cycle assessment.

#11: corporate sustainability management: winegrowing; table grape; tendone system; life cycle assessment; life cycle costing; italy

#14: sustainable food supply chain: extensive winegrowing; vine landrace; financial sustainability; wine industry; emergy evaluation; **supply chain quality**; wine industry; quality sustainability; emergy evaluation; extensive winegrowing**.**

The inclusion and exclusion criteria used for the literature review are showed in the **Table 2**.

Table 2. Inclusion/Exclusion criteria for literature review

Inclusion Criteria
• Only documents published in scientific journals.
• Studies that consider sustainability from the perspective of the agri-food supply chain and/or the wine supply chain.
• Studies that consider sustainability from the standpoint of environmental management and/or environmental impact, and food safety in wineries.
Exclusion Criteria
• Studies referring to the socioeconomic or political aspects of the concept of sustainability such as sustainable tourism in wine.
• Studies related to the ecology of cultivation, crop science, crop protection such as those related to soil science or irrigation techniques in the vineyard.
• Studies related to circular economy, packaging, life cycle assessment of wine.
• Studies related to nutrition or bio-components.
• Studies related to business performance or business models of wineries.

According with these criteria, the keywords nodes that were considered in the clusters were “environmental certified management standards,” “sustainable wine production,” “environmental sustainability,” “agri-food chains,” “environmental impact,” and “supply chain quality.”

A total of forty-five articles were deemed suitable. The abstracts were read, and based on this reading, 39 articles were discarded, mainly because they did not focus on sustainability based on supply chain management (n = 20), were not studies centred on wine production (n = 8) or were outside the scope of sustainability based on FS or EM (n = 11).

A collection of studies relevant to the central theme of this thesis was examined as part of the prior research. These studies investigate the connection between the FSMS and EMS tools in wineries and their use to evaluate sustainable practices in the wine production.

2.1.2 The sustainability framework in the EU Agriculture Sector

Leveraging insights from Vågsholm et al. (2020) this section explores the intricate relationship between agricultural practices and their environmental sustainability impacts (Vågsholm, Arzoomand, & Boqvist, 2020). Vågsholm and colleagues critically examine the convergence of food security, safety, and sustainability, framing these objectives within the pressing need for agricultural systems to adapt to and mitigate the effects of climate change, chemical use, and resource depletion. Their comprehensive review underscores the significant environmental footprint of conventional farming practices, including the extensive use of pesticides and fertilizers, which not only challenge biodiversity but also contribute to greenhouse gas emissions and water resource depletion.

This narrative emphasizes the pivotal role of sustainable farming techniques, such as organic agriculture and agroecological practices, as essential pathways toward mitigating these environmental challenges. By highlighting the ambitious goals of the EU Biodiversity Strategy for 2030 (European Commission, 2020a; European Commission, 2020b), including the transition toward organic farming, the discussion aligns with the broader ambitions of the European Green Deal and its F2F strategy (European Commission, 2020c). It stresses the critical balance needed between enhancing food production to meet global demands and preserving the ecological integrity of agricultural landscapes.

In doing so, this section not only reflects on the potential of sustainable agricultural practices to significantly reduce environmental impacts but also on the necessity for a systemic shift in how food production is approached. The insights from Vågsholm (2020) serve as a foundation for advocating a comprehensive approach to agricultural sustainability that incorporates food safety, security, and environmental stewardship within the EU policy frameworks and agricultural innovation.

The European Green Deal, along with its farm to fork strategy, positions agriculture at the forefront of the continent's sustainability ambitions, recognizing its role beyond mere economic contributions. It envisions agriculture as a cornerstone of social well-being, ecosystem health, and food and nutrition security (European Commission, 2019a; European Commission, 2019b). This comprehensive approach, however, confronts the reality of ongoing environmental degradation—biodiversity loss, excessive water use, and rising greenhouse gas emissions—despite the considerable investments funnelled into the common agricultural policy and other related EU policies. Furthermore, the enduring issues of rural abandonment and the erosion of rural heritage underscore the challenges facing Europe's countryside.

The European Union's Biodiversity Strategy for 2030 (BS30) represents a pivotal component of the broader European Green Deal, setting ambitious targets to protect nature and reverse the degradation of ecosystems. Within this strategic framework, agriculture in the EU stands at a crossroads, facing the dual challenge of contributing to biodiversity conservation while ensuring food security and rural livelihoods. (European Commission, 2020a; European Commission, 2020b).

The BS30 explicitly recognizes the critical role of agriculture in conserving biodiversity. The strategy calls for the transformation of agricultural practices towards more sustainable models, promoting agroecology, organic farming, and the preservation of high-diversity landscape features within farmlands (European

Commission, 2020a). Such integration is essential, as agriculture covers a significant portion of EU land and has profound impacts on habitats, soil, water, and air quality (Pe'er et al., 2020).

The BS30 outlines specific targets that directly involve the agricultural sector, including a commitment to ensure that at least 25% of EU farmlands are under organic farming by 2030, and the reduction of chemical pesticide use by 50% (European Commission, 2020a). These targets not only aim to reduce the environmental footprint of agriculture but also offer opportunities for farmers to diversify income sources and increase resilience to climate change and market fluctuations (Smith et al., 2013).

Despite the clear benefits, the transition towards biodiversity-friendly agriculture poses several challenges. Firstly, the adoption of sustainable practices requires significant investment in knowledge, skills, and infrastructure, which can be prohibitive for small-scale and marginal farmers (Hermoso et al., 2022). Moreover, there is a concern regarding the potential trade-offs between biodiversity objectives and food production, particularly in regions where agricultural intensification is seen to meet growing food demands (Delzeit, Zabel, Meyer, & Václavík, 2017; Hanspach et al., 2017).

The European Union F2F strategy, at the heart of the European Green Deal, heralds a transformative approach towards creating sustainable, fair, and healthy food systems. It addresses key production organization aspects in agriculture, encompassing crop and livestock farming alongside broader production systems, with a clear focus on reducing environmental impacts associated with pesticide use, nutrient management, antimicrobial use in livestock, and fostering the growth of organic farming (European Commission, 2020c).

In 2023, European Union agriculture demonstrated a significant reliance on both organic and inorganic fertilizers, with approximately ten million tonnes of nitrogen-based and around 1.1 million tonnes of phosphorous-based fertilizers utilized in 2021. France emerged as the top consumer of these fertilizers, underlining its prominent role as a leading agricultural producer in the EU. The application of inorganic fertilizers per hectare of agricultural land saw a 10.1% increase from 2010 to 2020, with significant rises observed in Bulgaria, Greece, Romania, and Hungary. Conversely, Germany experienced the most substantial decrease in usage (Eurostat, 2023).

Pesticide usage represents a crucial concern, witnessing a 38% reduction in associated risks by 2021 when compared to the average for 2011-2013. Nevertheless, the evolving nature of active substances in pesticides means that sales volume alone does not fully encapsulate the potential hazards. Approximately 356,000 tonnes of pesticides were sold throughout the EU in 2021, with Germany, Spain, and France leading in consumption of various pesticide types (Eurostat, 2023).

The strategy's dedication to reducing reliance on chemical pesticides is part of a wider move towards sustainability, recognizing the adverse effects of pollution on soil, water, and air. This dedication is reflected in the EU's significant move towards reducing chemical pesticide use, despite an opposing trend of increased overall chemical input due to the intensification and specialization of the sector. (Prandecki, Wrzaszcz, & Zieliński, 2021).

Furthermore, the F2F strategy prioritizes the management of fertilization, aiming to mitigate the pollution from excess nutrients, which poses a significant threat to biodiversity and climate. It proposes strategies to optimize fertilizer application, ensuring soil fertility while balancing environmental protection needs. This reflects a nuanced fertilization practice landscape across the EU, highlighting regions of progress and areas still grappling with nutrient over-application (Billen et al., 2024).

Addressing antimicrobial resistance, the strategy sets forth objectives to curb antimicrobial use in livestock, reflecting a broader trend of decreasing livestock populations and a shift towards specialized farming operations (Martin et al., 2020). This is critical for maintaining animal health and preventing resistance, in line with European Surveillance of Veterinary Antimicrobial Consumption data highlighting shifts in antimicrobial usage patterns (More, 2020).

F2F strategy advocates for the adoption of circular economy principles to significantly reduce waste generation across agriculture, forestry, fishing, and the food and beverage processing sectors. In 2020, these sectors collectively produced 55.3 million tonnes of waste, representing 2.8% of the total waste from productive activities within the EU. A notable achievement within this framework has been the reduction of waste from the F&B processing sector by almost 23% from 2010 to 2020. Moreover, food waste presents a considerable challenge, with an indicative average of 131 kilograms of fresh mass collected per person in the EU in 2021, more than half of which originated from household sources (Eurostat, 2023).

Organic farming is underscored as a vital component of the F2F and Biodiversity strategies, promoting environmental sustainability (Paull, 2024). The growth of organic farming across the EU indicates its rising importance and potential in achieving the Green Deal's objectives, despite its niche status within the broader agricultural landscape. The move towards larger, more specialized organic operations suggests evolving dynamics focused on enhancing production potential and environmental benefits.

The European Union's adoption of the European Climate Law marks a watershed moment in its commitment to achieving climate neutrality by 2050. This legislative framework sets binding targets to reduce net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels, and to reach net-zero emissions by 2050 (European Parliament, 2021a). Agriculture, as a significant source of methane and nitrous oxide emissions, is both impacted by and pivotal to the EU's climate ambitions (Gołasa et al., 2021).

In 2023, agriculture was responsible for 10.7% of the European Union's greenhouse gas emissions, marking a 21.9% decrease in emissions from 1990 (Eurostat, 2023). Most of these emissions were methane and nitrous oxide, predominantly originating from livestock and agricultural soils cultivation (Mielcarek-Bocheńska & Rzeźnik, 2021; Simionescu, Bilan, Gędek, & Streimikiene, 2019). Notably, enteric fermentation, soil management, and manure management played significant roles in these emissions. From 1990 to 2021, emissions from these sources experienced reductions of 20.5% from soils, 21.4% from manure management, and 23.0% from enteric fermentation (Eurostat, 2023). However, if food production and processing are included in the "agrifood industry," the percentage can be significantly higher, as this sector encompasses a wide range of activities ranging from agricultural production to the processing, packaging, transportation, and sale of food.

The European Climate Law calls for a shift in agricultural practices towards sustainability, efficiency, and innovation to lower these emissions. For instance, the law supports the reduction of methane emissions through improved livestock management and the adoption of precision farming techniques to minimize fertilizer use, thereby reducing nitrous oxide emissions (Li, Xu, Hu, & Han, 2014; O'Mara, 2011; Oenema et al., 2014).

The European Climate Law urges the adoption of climate-smart agricultural practices to enhance resilience, carbon sequestration, and emission reduction. Practices such as agroforestry, organic farming, and the restoration of peatlands and wetlands not only mitigate climate change but also improve biodiversity, soil health, and water quality, offering multiple benefits for environmental sustainability (Lal, R. et al., 2011; Lal, Rattan, 2016). Moreover, the law encourages the development of a bio-based economy, placing agriculture at the forefront of renewable energy and material production, creating new opportunities for farmers (European Parliament, 2021a; Ingrao et al., 2018).

The impact of climate change exacerbates the pressures agriculture places on the environment and natural resources, threatening the very foundation of food systems (Myers et al., 2017; Vermeulen, Campbell, & Ingram, 2012). The paradoxical nature of some sustainability strategies becomes apparent when efficiency improvements, while beneficial in reducing waste and nutrient loss, risk perpetuating a cycle of unsustainability if narrowly focused on farm-level optimizations. Herein lies the potential of agroecology, which offers a reimagined approach to traditional practices, aiming to harmonize agricultural production with ecological principles. However, transitioning to such practices raises numerous questions about feasibility, scalability, and impact (International Panel of Experts on Sustainable Food Systems (IPES-Food), 2022).

Agriculture role in a sustainable future inquiries challenge to envision an agricultural system that supports not only the production of food but also contributes positively to societal health, environmental resilience, and cultural heritage. It becomes clear that achieving a sustainable agricultural system requires a multifaceted strategy. One that integrates innovative technologies and practices with the wisdom of traditional farming methods, ensuring food security while protecting the planet. It calls for policies that not only incentivize sustainable practices but also support the social fabric of rural communities, preserving their heritage and way of life. Moreover, this transition towards sustainability must be inclusive, engaging all stakeholders—farmers, consumers, policymakers, and researchers—in a collaborative effort to redefine the value of agriculture in society. By doing so, agriculture can transcend its traditional boundaries, becoming a key player in the fight against climate change, a protector of biodiversity, and a guarantor of food and nutrition security (European Environment Agency, 2022).

Agriculture sector significantly influences Europe's water resources, facing challenges despite notable improvements. Over recent years, efforts to mitigate these impacts have led to a 20% reduction in nitrate concentrations in rivers and a 25% decrease in agricultural water abstraction. However, these pressures remain unsustainable in many areas, with agriculture accounting for up to 60% of net water use across the EU (Eurostat, 2023). The changing climate further complicates this scenario, as altered precipitation patterns and rising temperatures exacerbate existing water resource pressures. In response, a gradual shift towards sustainable practices is evident, with 7.5% of the EU's agricultural land now dedicated to organic farming (Eurostat, 2023).

The main milestones in agriculture and sustainability in the past five years are showing in **Table 3**.

Table 3. Main milestones in agriculture and sustainability in the past five years

Date	Event	Description	References
11 December 2019	Presentation of the **European Green Deal**	Introduction of a comprehensive plan aiming to make the EU's economy sustainable by turning climate and environmental challenges into opportunities.	(European Commission, 2019a; European Commission, 2019b)
20 May 2020	Presentation of the EU **Biodiversity Strategy 2030** and **the "Farm to Fork Strategy"**	Strategies aimed to protect natural resources and make food systems more sustainable, as part of the European Green Deal.	(European Commission, 2020a; European Commission, 2020b; European Commission, 2020c)
9 July 2021	Publication of the **European Climate Law**	Establishes the goal of achieving climate neutrality by 2050 and sets a target to reduce GHG emissions by at least 55% by 2030.	(European Parliament, 2021a)
17 November 2021	Adoption of the **EU Soil Strategy for 2030**	Aims to promote sustainable soil management practices to protect soil health, preserve biodiversity, and reduce carbon emissions from soils.	(European Commission, 2021b)
14 December 2020	Adoption of the **EU Next Gen** recovery and resilience plan	A financial plan to support EU partner countries in accelerating the green, digital, and health transitions.	(Council of the European Union, 2020)
2 December 2021	Formal adoption of a new and more ambitious CAP **Common Agricultural Policy (CAP) 2023+**	Sets the direction for agricultural policies starting in 2023, with a focus on sustainability and innovation.	(European Parliament, 2021b)
31 August 2022	Formal approval of CAP Strategic Plans by the Commission *- Spain CAP Strategic Plan was approved **8 September 2022** -*	Approval of national plans for implementing the new CAP, indicating how each EU country will apply the policy at the national level starting in 2023.	(European Commission, 2022a; European Commission, 2022b)
5 July 2023	Initiative for a **Soil Health Law**	Proposes to grant soils the same level of legal protection as air and water, emphasizing soil conservation and health.	(European Commission, 2023a; European Commission, 2023b)

2.1.3 Agrifood industry sustainability

Agrifood industry faces numerous sustainability challenges, encompassing environmental, social, and economic aspects that affect the entire process of food production, distribution, and consumption (Sadiku, Musa, & Ashaolu, 2019; Yadav, Singh, Gunasekaran, Raut, & Narkhede, 2022). To tackle these complexities, it is necessary for the agrifood industry to implement sustainable practices that align with economic feasibility, social justice, and environmental preservation (Hammoudi, Hoffmann, & Surry, 2009; Lezoche, Hernandez, Díaz, Panetto, & Kacprzyk, 2020; Luo, Ji, Qiu, & Jia, 2018). Agrifood industry is currently in its initial stages of embracing sustainability practices. Several studies have shed light on the challenges and opportunities that agrifood firms encounter in relation to promote sustainability. However, given the growing complexity of this sector, there is a pressing need to establish more structured methodologies that incorporate sustainability considerations (Barth, Ulvenblad, & Ulvenblad, 2017).

Sustainability in the ASC emerges from the four dimensions encompassed within the ASC Performance (Aramyan, Oude Lansink, van der Vorst, & van Kooten, 2007). ASC represents the comprehensive range of activities involved in the handling of agricultural food, spanning from producers and farmers to end consumers (Joshi, Singh, & Sharma, 2020). Aramyan et al. (2007) propose four primary performance dimensions, namely, efficiency, flexibility, responsiveness, and food quality. Furthermore, an additional category is introduced to encompass a wide array of critical aspects that reflect the social and environmental dimensions of sustainability (Varsei, Soosay, Fahimnia, & Sarkis, 2014). In refining the sustainability dimension, Gold (2017) delineate indicators such as local living conditions, labour rights, land rights, FS, end-of-life valorisation through biomass recycling, and environmental issues (Gold, Kunz, & Reiner, 2017). From a consumer perspective, sustainability encompasses credibility attributes inherent in the food products they consume. Consequently, agri-food industries allocate a substantial portion of their resources toward advertising and marketing initiatives focused on sustainability (Rondoni & Grasso, 2021; Schäufele & Hamm, 2017).

Within the context of analysing the sustainability of agri-food production, indicators pertaining to FS and EM prove to be invaluable components of the Sustainability dimension in ASC performance. Given the resource-intensive nature of wine production and its potential environmental repercussions on the surrounding ecosystems, ensuring robust FS measures and effective EM becomes paramount for the sustainability of the agro-industrial environment (Baiano, 2021; Liu, 2018).

FS is a crucial aspect of the agri-food sector, as it has a direct impact on consumer health and the reputation of the industry (Maloni & Brown, 2006). Adopting Good Manufactural Practices (GMP) and implementing Hazard Analysis and Critical Control Points (HACCP) systems are essential measures to prevent food contamination and maintain FS (Bauman, 1995). The use of these practices and systems helps to monitor the food supply chain and identify potential risks, allowing the industry to proactively address and prevent FS issues (Bertolini, Bevilacqua, & Massini, 2006; Moe, 1998; Wang, Yue, & Zhou, 2017). Additionally, the implementation of FS management systems, such as the GFSI or HACCP, can enhance the industry's overall FS practices and ensure the provision of safe and wholesome food to consumers (Crandall et al., 2012; Sansawat & Muliyil, 2011).

As a dimension of sustainability, FS includes contamination, spoilage, and the presence of hazardous substances. These issues have significant impacts on both human health and the environment. In Spain, the contamination of food products with pathogenic microorganisms has been a persistent issue. According to several research studies, a high percentage of raw and processed foods in Spain were found to be contaminated with Salmonella, Listeria, and E. coli, posing a serious threat to public health (González-Angulo et al., 2021; Karimi, 2022; Porto-Fett et al., 2022). In Malaysia, the use of toxic pesticides and fertilizers in agriculture has been identified as a significant contributor to FS concerns (Harun, Hanafiah, & Aziz, 2021; Lai, Settinayake, Yeo, Lau, & Jong, 2019).

The environmental dimension of sustainability is an important concern in agrifood. The agri-food sector has a significant impact on the environment, impacting resource utilization such as water and energy, and contributing to greenhouse gas emissions, waste production, and pollution (Godfray & Garnett, 2014).

Environmental issues have emerged as a significant sustainability factor in agrifood. Agricultural and food industry activities have been shown to have adverse environmental impacts, such as greenhouse gas emissions (Panchasara, Samrat, & Islam, 2021; Sharma, Shah, Shahzad, Jain, & Chopra, 2021; Yoro & Daramola, 2020), soil erosion (Chalise, Kumar, & Kristiansen, 2019; Kopittke, Menzies, Wang, McKenna, & Lombi, 2019; Tsoraeva, Bekmurzov, Kozyrev, Khoziev, & Kozyrev, 2020), water pollution (Bashir et al., 2020; Rathi, Kumar, & Vo, 2021; Uddin & Jeong, 2021; Ukaogo, Ewuzie, & Onwuka, 2020), and waste generation (Tubiello et al., 2021), which can have long-term impacts on the ecosystem and human health (Alengebawy, Abdelkhalek, Qureshi, & Wang, 2021; Kalyabina, Esimbekova, Kopylova, & Kratasyuk, 2021). Food industry causes severe environmental impacts as greenhouse gas emissions, energy consumption It is estimated that the food systems produce 20-40% of the anthropogenic greenhouse gas emissions from all economic activities (Rosenzweig et al., 2020; Vermeulen, Campbell, & Ingram, 2012). The food industry has been identified as one of the industries where climate change adaptation is of high importance (Fleming et al., 2014; Ridoutt et al., 2016).

Food industry is under growing pressure to decrease its environmental impact and align with sustainability targets (Eldesouky, Mesias, & Escribano, 2020; Rodríguez-Rodríguez, Galdeano-Gómez, Carmona-Moreno, & Godoy-Durán, 2012; Salim et al., 2018b). Food industry contributes to waste generation, both in terms of food waste and packaging waste. Waste management is an area where the food industry can have a significant environmental impact. The generation of food waste is a growing concern, as it results in the loss of valuable resources and contributes to greenhouse gas emissions through landfilling (Aldaco et al., 2020; Derqui, Fayos, & Fernandez, 2016; Mena, Adenso-Diaz, & Yurt, 2011). The management of food waste is also a challenge, with a significant portion of food waste being disposed of in landfills, leading to environmental degradation and the release of methane, a potent greenhouse gas (Jereme, Siwar, Begum, & Talib, 2016; Lim, Chin, Yusof, Yahya, & Tee, 2016). Water management is a challenge in the food as the production of food requires significant amounts of water, particularly in agriculture. One of the major environmental challenges faced by the food industry is water scarcity. Irrigation practices in agriculture account for substantial water usage, which can lead to water depletion and degradation of water quality (Garcia-Caparros, Contreras, Baeza, Segura, & Lao, 2017; Mateo-Sagasta, Zadeh, Turral, & Burke, 2017). On the other hand, water pollution resulting from agricultural activities, such as the use of pesticides and fertilizers, poses a threat to freshwater resources and aquatic ecosystems (Afroz, Masud, Akhtar, & Duasa, 2014; Mahmood, Imadi, Shazadi, Gul, & Hakeem, 2016).

Agriculture and food processing are significant contributors to global greenhouse gas emissions, particularly in terms of emissions from livestock production and fertilizer use (Steinfeld et al., 2006). Addressing these emissions requires the implementation of mitigation strategies, such as the adoption of low-carbon technologies and sustainable land management practices (Gielen et al., 2019; Valin et al., 2013). Agrifood industry is responsible for a sizeable portion of the country's total emissions, and efforts are being made to reduce these emissions through the implementation of sustainable practices and the use of renewable energy (Appolloni, Jabbour, D'Adamo, Gastaldi, & Settembre-Blundo, 2022). The increasing demand for animal-based products is driving an increase in emissions from livestock production, and reducing these emissions is a significant challenge for the country's agri-food sector (Banhazi et al., 2012; Zayadi, 2021).

2.1.4 Wine industry sustainability

In addressing the dual challenge of bolstering food security while advocating for environmentally sustainable agricultural practices, it becomes imperative to weave in the critical insights from Epuran (Epuran, Bratucu, Bărbulescu, Neacşu, & Madar, 2018) and Gilinsky Jr et al. (2016) (Gilinsky Jr, Newton, & Vega, 2016). These perspectives shed light on the multifaceted nature of sustainability in the wine industry and its implications for broader agricultural paradigms. Epuran et al. (2018) bring to the forefront the nuanced understanding that while the adoption of sustainability principles is acknowledged within the wine sector, their strategic incorporation from a comprehensive standpoint remains limited. This observation underscores the need for innovative approaches that not only enhance the environmental footprint of agriculture but also ensure the production of safe, nutritious food.

Similarly, Gilinsky Jr et al. (2016) highlight the pivotal role that sustainable practices play in offering a competitive edge and enhancing business performance within the wine industry. This insight is crucial in understanding that sustainability and food safety are not mutually exclusive but are interdependent aspects that can drive industry-wide transformation. By adopting sustainable practices, businesses can contribute to the broader goals of food safety, through more efficient use of resources and reducing the environmental impact of food production.

The wine industry impact extends well beyond just vineyards and wineries, encompassing a broad array of activities and sectors from nursery operations and agrochemical products to packaging or logistics.

The International Organization of Vine and Wine (OIV) characterizes a sustainable grape and wine industry as an overarching strategy that includes the economic viability of operations and regions, the production of quality products, and the incorporation of sustainable viticulture practices. It also highlights the importance of minimizing environmental risks, ensuring product safety and consumer health, and preserving cultural, historical, ecological, and scenic values (Organisation Internationale de la Vigne et du Vin, 2004).

The OIV has adopted a resolution outlining the general principles of sustainable viticulture and oenology, which includes considerations for the impact of industry operations on the socioeconomic landscape and their contribution to the development of local territories. This resolution addresses working conditions, integration with the local socio-economic and cultural context, consumer health and safety, and underlines the importance of safeguarding employee health and safety, providing ongoing training, and maintaining workforce stability (Organisation Internationale de la Vigne et du Vin, 2016; Organisation Internationale de la Vigne et du Vin, 2022).

Meissenheimer (2001) have classified WSC into distinct categories, which encompass various activities. These activities comprise soil and plant material management, vineyard practices, cellar practices and wine production, packaging and distribution and market development and marketing (Meissenheimer, Karaan,

& Vink, 2001). WSC encounter a range of challenges that can be categorized into three principal areas. These challenges include global and environmental challenges, methodological and financial challenges and challenges associated with the economy and the market (Goncharuk, 2017).

The WSC sustainability has gained significant relevance in recent years, given the growing interest in environmentally friendly agricultural and viticultural practices. This concept refers to the ability to maintain wine production in the long term without compromising natural resources or harming the environmental context in which it takes place. According to Luzzani (2021), wine industry sustainability encompasses a broad range of aspects (i.e. field operations, grape transformation, cultural and traditional heritage of wine) (Luzzani, Lamastra, Valentino, & Capri, 2021).

Given the labour-intensive nature of the wine industry, the social dimension of WSC sustainability cannot be overstated. Factors such as worker well-being, education and working conditions, social protections, and ethical practices are crucial (Forbes, De Silva, & Gilinsky, 2020; Martucci, Arcese, Montauti, & Acampora, 2019).

Besides, the WSC significantly contributes to the EU environmental sustainability through various means, including enhancing biodiversity, reducing soil erosion, improving water management, and providing fire protection. Vineyards create diverse ecosystems by hosting a variety of plants and animals and incorporating sustainable farming practices, such as planting cover crops and minimizing chemical use. These practices not only support local wildlife but also promote biodiversity in vineyard areas. For instance, a research in Rhinehessen, Germany, aimed at increasing biodiversity on steep slopes, resulted in a notable increase in butterfly, plant, and bee species (Uzman, Reineke, Entling, & Leyer, 2020).

Soil erosion, a major concern in agriculture, is mitigated in vineyards through practices like cover cropping and erosion control techniques, which stabilize the soil and prevent erosion (López-Vicente, Calvo-Seas, Álvarez, & Cerdà, 2020). These practices have been shown to reduce soil erosion significantly compared to traditional tilling methods. Additionally, the wine sector employs water-saving irrigation techniques, advanced technology for water management, and rainwater collection for irrigation, contributing to sustainable water management and conservation in regions facing water scarcity (Novara, Cerda, Barone, & Gristina, 2021).

Furthermore, vineyards can serve as firebreaks, offering protection against wildfires. The bare ground between vine rows can halt the rapid spread of fires, and controlled burning techniques further reduce fire risk. In the Spanish wine region of Priorat, a project offering irrigation advice to wineries and winegrowers resulted in significant water savings, showcasing the sector's role in environmental conservation (Ascoli et al., 2023).

Additionally, Delmas (2021) highlight how sustainable farming practices can not only improve the environmental sustainability of viticulture but also increase the safety and quality of wine products, emphasizing the importance of complete traceability from the vineyard to the table (Delmas & Gergaud, 2021).

However, studies like those by Baiano et al. (2021) and Wagner (2023) highlight the need to optimize the use of water and energy, and to minimize the use of pesticides and fertilizers to reduce the carbon footprint associated with wine production, marking a path towards more sustainable practices in European viticulture (Baiano, 2021; Wagner et al., 2023).

Environmental issues and poisonings caused by wine production, such as water pollution due to the excessive use of pesticides and fertilizers, have led to the implementation of stricter environmental standards. Poisoning issues related to wine production, such as cases of methanol and other chemical contaminants, have highlighted the need for rigorous quality control. Concerns over the presence of pesticides in wine, for example, have led the European Union to establish maximum residue limits to ensure the safety of wine products consumed within its borders (European Commission, 2006; European Commission, 2014; European Commission, 2015; European Commission, 2021a; European Parliament, 2005).

The European Union has implemented a series of legislations to address these challenges, including Regulation (EU) No 1308/2013, which sets specific standards for the wine sector in terms of production and labelling (Carrión & Moyano, 2023). Additionally, Regulation (EC) No 852/2004 on the hygiene of foodstuffs requires that all food production operations, including wine production, comply with food hygiene principles to ensure the safety of the final product (Álvarez, 2021). Also, Directive 2000/60/EC of the European Parliament and of the Council of the European Union, also known as the Water Framework Directive, establishes a framework for the protection of surface water and groundwater, directly affecting the wine industry by promoting the sustainable use of water resources (European Parliament, 2000).

These regulations underscore the importance of adopting wine production practices that are not only environmentally sustainable but also safe for human consumption, to ensure a proper balance between environmental sustainability, food safety, and economic competitiveness in the wine industry. Adapting to these regulations and mitigating negative environmental impacts are fundamental for the future of a sustainable and responsible wine industry on a global level. To achieve this goal, it is essential to consider both FSMS and EMS throughout the production process.

2.2 Food safety management

According to European food legislation, "foods shall be deemed unsafe if they are harmful to health or unfit for human consumption" (European Parliament & European Council (2002), 2002). FS occurs when "all people, always, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (Food and Agriculture Organization, 2011).

This concept has grown in importance in recent decades, extending not only to food but also to all links in the food chain, from primary production through processing, manufacturing, handling, and packaging to the sale to consumers and the preparation of food by the final consumer.

A food hazard is considered as any physical, chemical, or biological agent that can contaminate our food, while a food risk is the probability of the occurrence of any of the mentioned hazards combined with the severity of the harm they can cause to the consumer in the event of an incident.

2.2.1 Critical Control Points

According to Lee, a critical control point (CCP) "is a point in a step or procedure at which a control must be applied for the prevention or elimination of a hazard or reduction to an acceptable level" (Lee, S., Han, Yoon, & Lee, 2022). Critical control points (CCPs) are identified, evaluated, and controlled at each stage of the food production processes using the HACCP tool. After significant food hazards identification, it is assessed whether they constitute a critical control point. If they are assessed as CCPs, then critical limits must be set by applying preventive measures, so that there are no deviations in these established limits (Bauman, 1995; European Commission, (2016), 2016; Sperber, 1992).

The system for identifying CCPs follows the type of decision canvas shown in **Figure 4**. This figure facilitates the determination of CCPs through four sequential questions. Conducting a hazard analysis of CCPs enables the identification, evaluation, and control of significant CCPs throughout the food production process. Once potential hazards are identified, their status as a CCP is assessed, and reference limits or critical limits are established through the implementation of preventive measures to prevent deviations from these limits (Bauman, 1995; European Commission, (2016), 2016; Sperber, 1992). Identification of CCPs is executed by employing the decision tree framework as outlined by Codex Alimentarius, which was further tailored with ISO 22000: 2018 (E) criteria (International Organisation of Vine and Wine, 2020). This procedure helps determine whether the hazards can be effectively addressed as Operational Prerequisite Program (oPRPs) or whether specific operational protocols, including defined measures, are required for the management of CCPs (Chen, H. et al., 2020; International Organisation of Vine and Wine, 2020).

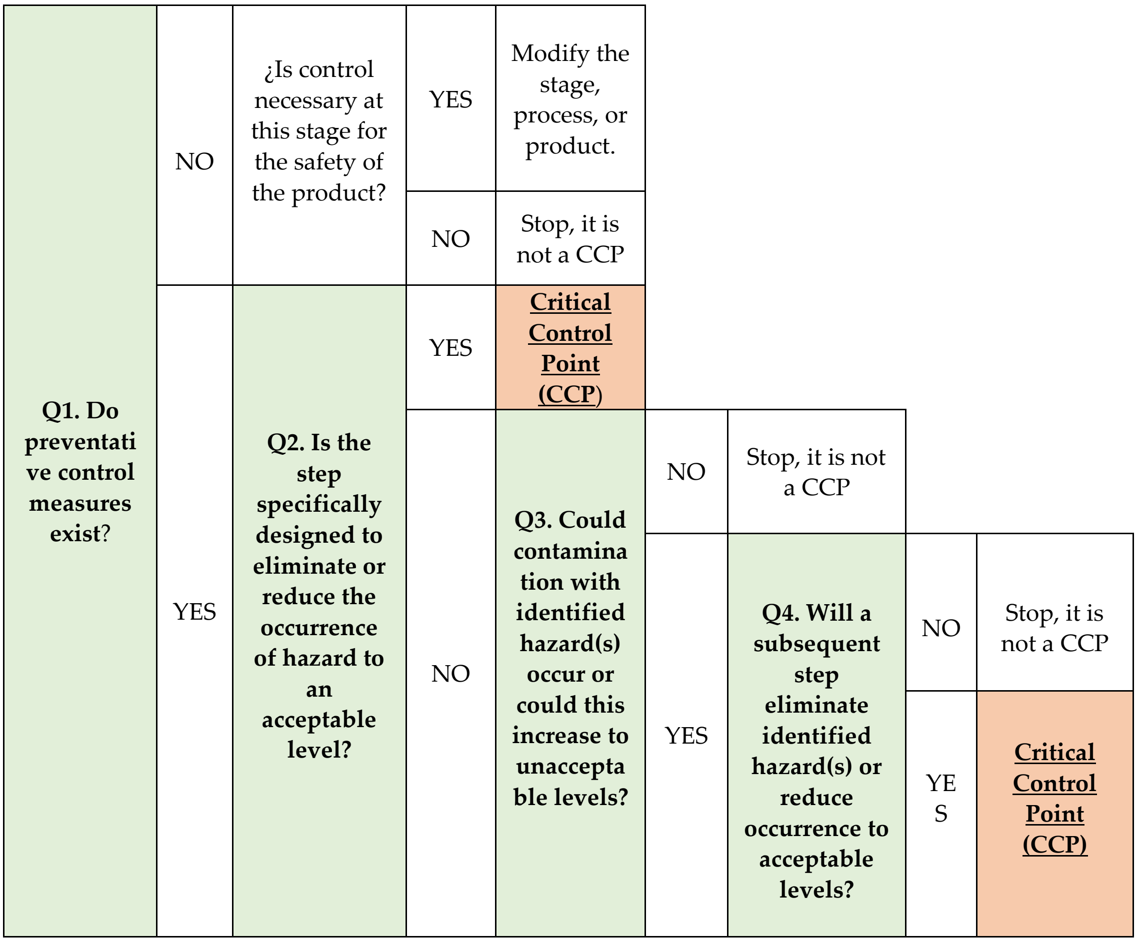

Figure 5. Decision canvas to identify CCPs. Source: On work, based on Commission Notice of FSMS (European Commission, 2016).

2.2.2 Hazard Analysis Critical Control Point and Prerequisite Programs

The Hazard Analysis and Critical Control Point (HACCP) system is defined as a preventive program focused on the production of safe food products (Christaki & Tzia, 2002). The HACCP system originated in 1959 when Pillsbury, along with the United States Army and the National Aeronautics and Space Administration (NASA), developed a program to produce safe food for astronauts. The most significant diseases that could affect the astronauts were related to the food they would consume (Bauman, 1995). Pillsbury introduced HACCP as the system that could offer the highest level of FS because it controlled the entire production process from the beginning of the processing chain. The HACCP program had only three principles in its origins, but it currently has seven.

The National Academy of Sciences (NAS) (National Research Council, 1985) and the National Advisory Committee on Microbiological Criteria for Foods (NACMF) is responsible for this expansion and its subsequent adoption by the Codex Alimentarius in 1993.

In 2003, a global consensus was reached for the use of HACCP in the global food supply. The Codex Alimentarius Food Hygiene Committee of the World Health Organization issued the HACCP guidelines for International Trade (Codex Alimentarius Commission, 2011). Soon after, the European Union, Canada, Australia, and Japan issued regulations requiring food businesses to develop and to implement FS plans based on the NACMCF and the Codex Alimentarius frameworks (Bernard & Scott, 2007).

Nowadays, the HACCP method is an internationally recognized systematic approach to food security that seeks to comply with the development and the realization of effective FS practices (Mortimore & Wallace, 2013). It is based on seven principles that identify and control FS hazards (**Table 4**) (Dominguez, Espinosa, Dominguez, & Romero, 2021; Mortimore & Wallace, 2013).

In addition, HACCP ensures that appropriate corrective actions are taken, where necessary, and that a registration system is available for documentation (Gehring & Kirkpatrick, 2020). Under these principles, if any deviation occurs, it indicates that control has been lost. In that case, it is of paramount importance taking appropriate steps to restore control and to ensure that potentially dangerous products do not reach the consumer (Hulebak & Schlosser, 2002).

An HACCP program is required to be built on a solid foundation of previous programs called prerequisite programs (PRPs) (Vela & Fernández, 2003). In accordance with what is described in the Codex Alimentarius (Codex Alimentarius Commission, 2011), PRPs are based on the general principles of food hygiene (European Parliament, 2004).

Table 4. Key principles of HACCP.

Number	Principle	Description
Principle 1	Perform a hazard analysis	Hazards should be identified and the associated risks that accompany them should be assessed at each stage of the production system and control measures should be described.
Principle 2	Determine CCPs	CCPs must be determined.
Principle 3	Set critical boundaries	A critical limit must be associated with each control measure to ensure that CCPs are under control.
Principle 4	Establish a surveillance system	A surveillance system should be implemented to ensure that CCPs are within critical limits and therefore under control
Principle 5	Establish corrective measures	Corrective measures to be taken when the surveillance system detects that a CCP is outside the control limits should be established
Principle 6	Establish verification procedures	Verification procedures should be established to con-firm that the HACCP is functioning effectively and correctly.
Principle 7	Establish a system of registration and documentation	A system of record should be established on all procedures performed and the associated records.

Thus, PRPs provide basic environmental and operating conditions that are necessary to produce safe and healthy food. They address issues related to the cleaning and the disinfection of facilities and equipment, the supply and the use of supply water, pest prevention and control, staff handling practices and knowledge of FS, and the identification and the location of food produced and marketed (European Commission, (2016), 2016; Panghal, Chhikara, Sindhu, & Jaglan, 2018); PRPs are built with different types of programs that develop each issue.

While the HACCP focuses on the dangers that depend solely on the production process, PRPs seek to eliminate all those dangers that depend on the work environment. The application of HACCP has advantages, but it also has certain drawbacks. The main advantages from its application are guaranteeing FS, allowing the control of each of the phases of the food chain that intervenes in the elaboration of a product, facilitating the supervision of the system by competent authorities, and its application to all food companies, regardless of their size or activity.

However, HACCP presents certain drawbacks, such as the need for: specific technical and material resources that are not always available to the industry; the training and the commitment of industry employees; methods for determining difficult CCPs (Panisello & Quantick, 2001); and continuous evaluation and analysis of data (Vela & Fernández, 2003).

2.2.3 FS management in wine production

Grapes, must, and wines are susceptible to various hazards for consumer safety. These FS risks include physical hazards (metal parts, glass, insects), chemical hazards (pesticide residues, heavy metal residues, urea), and microbiological hazards (pathogens) that can affect consumer health (Christaki & Tzia, 2002).

For example, growing concern over contaminants in food, such as mycotoxins and fungicides, has led to stricter regulations and the need for analytical methods (Álvarez, Noguerol-Pato, González-Barreiro, Cancho-Grande, & Simal-Gándara, 2012). Fungicide residues in grapes pose health risks in winemaking (González-Rodríguez, Noguerol-Pato, González-Barreiro, Cancho-Grande, & Simal-Gándara, 2011). Ochratoxin A (OTA) is a nephrotoxin found in wine, with regional variations in occurrence (EFSA Panel on Contaminants in the Food Chain (CONTAM) et al., 2020; European Food Safety Authority, 2006; Otteneder & Majerus, 2000). OTA is classified as a possible human carcinogen (IARC, 1993) and constitutes a dietary concern (Valero, Marín, Ramos, & Sanchis, 2008). Analysing and regulating these contaminants is essential for ensuring FS (Brera, Soriano, Debegnach, & Miraglia, 2005).

Hazards in wine production can arise from the environment, processing equipment, and winery workers. However, the two common causes of major FS incidents are related to undeclared allergens and cross-contamination (Lee, S., Han, Yoon, & Lee, 2022). Hygienic conditions and practices are required to prevent the introduction of hazardous agents. In winemaking, the main hazardous agents are the increase in microbiological load or the accumulation of residues and other directly or indirectly produced chemical and/or physical agents. The types of PRPs depend on the winery in which the HACCP is going to be implemented, and they must be adapted in a specific way.

Christaki, T. (2002) identified main CCPs in red wine production (Christaki & Tzia, 2002). Benito, S. (2019) conducted a study on the identification and control of CCPs during winemaking to mitigate the levels of various compounds, including biogenic amines, ethyl carbamate, ochratoxin A, and sulfur dioxide (Benito, 2019). Martinez-Rodriguez (2009) studied CCPs associated with microbial safety during wine production, with a particular focus on Ochratoxin A (Martínez-Rodríguez & Carrascosa, 2009).

Table 5 shows main CCPs and oPRPs in the production of young wine based on previous research (Benito, 2019; Christaki & Tzia, 2002; International Organisation of Vine and Wine, 2020; Magan, 2006; Martínez-Rodríguez & Carrascosa, 2009). **Figure 6** shows a flow diagram of wine-making process and corresponding CCPs or oPRPs to each stage of this process based on technical document (Bermúdez Leirós, 2020) and **Table 5**.

When an inadequate control of critical points is carried out aimed at eliminating the food hazards related to the appearance of microorganisms, phytosanitary or traces of heavy metals, it means that both grapes and wine can be contaminated with these food hazards that endanger human health (Christaki & Tzia, 2002; Magan, 2006; Martinez-Rodriguez & Carrascosa, 2009).

FSMS play a crucial role in ensuring the production of safe and high-quality products in the wine industry. Spanish wineries have implemented various FSMS to meet regulatory requirements and maintain consumer trust.

Table 5. Main CCPs and oPRPs in the production of young wine.

Winemaking steps	**Critical Control Point & Operational Prerequisite Program**	
Harvest and grape transportation	oPRP 2.1	Vineyards inspection prior to the harvest to know the general condition of the grapes.
	oPRP 2.2	Vineyards inspection during the harvest to know the state of grapes.
	oPRP 2.3	Time control that takes to transport the harvest to the winery.
Harvest reception in winery	oPRP 3.1	Control of residues of fungicides and / or pesticides existing in grapes intended for winemaking.
	oPRP 3.2	Mycotoxins control from grape rot.
	oPRP 3.3	Control of the presence of contamination by plant debris, dust and / or metallic elements.
	CCP 3.1	Control of the presence of contamination by metals (Cd, Pb, As) in the grapes.
Pre-hatching treatments	oPRP 4.1	Control of the cleanliness of the tanks to eliminate residues of microorganisms.
	oPRP 4.2	Control of the absence of cleaning and disinfection products in the tanks.
Grape crushing and must pumping	oPRP 5.1	Control of the cleanliness of crushing equipment.
	oPRP 5.2	Control of the absence of cleaning and disinfection products in tanks, press and pumping equipment.
	CCP 5.1	Control of the wort maintenance time in the crusher.
Sulphited and vatted	oPRP 6.2	Control of the absence of microorganisms in equipment and tanks.
	CCP 6.1	Control of the safety and purity of additives
Alcoholic fermentation, maceration, vat emptying, pressing and malolactic fermentation	oPRP 7.1	Control of the concentration of ethylocarbamate in fermented must.
	oPRP 7.2	Control of hygiene during racking and pressing operations.
	oPRP 7.3	Control of the cleanliness of pressing equipment.
	CCP 7.1	Control of sulphur dioxide in fermented must.
	CCP 7.2	Control of the purity and safety of yeasts.
	CCP 7.3	Temperature control during fermentation.
	CCP 7.4	Control of the pH of red wine during malolactic fermentation.
Racking, clarification, and filtration	oPRP 8.1	Control of the cleaning procedures of tanks and transfer equipment.
	oPRP 8.2	Control of maintenance and cleaning procedures of the facilities.
	oPRP 8.3	Control of hygiene operations during clarification and filtering operations.
	oPRP 8.4	Control of the absence of cleaning and disinfection products in tanks and equipment.
	oPRP 8.5	Control of the absence of foreign elements from the filters in red wine.
	CCP 8.1	Control of the purity and safety of agents used as clarifiers in red wine.
	CCP 8.2	Control of the absence of residues of agents used as clarifiers in red wine.
Cold stabilization	CCP 9.1	Control of limit concentrations of metals (traces of As, Cu, Pb) in red wine.
	CCP 9.2	Control of the additives used are those allowed by current food legislation.
Bottling and labelling	oPRP 10.1	Control of bottle cleaning procedures.
	oPRP 10.2	Control of maintenance and cleaning procedures of the red wine bottling line.
	oPRP 10.3	Control of the correct coding of the labels used on the bottles.
	oPRP 10.4	Control of correct allergen information on labels used on bottles.
	CCP 10.1	Microbiological control of the bottling line of red wine and bottles.
	CCP 10.2	Microbiological control of the cork stopper or similar used for closing the bottles.

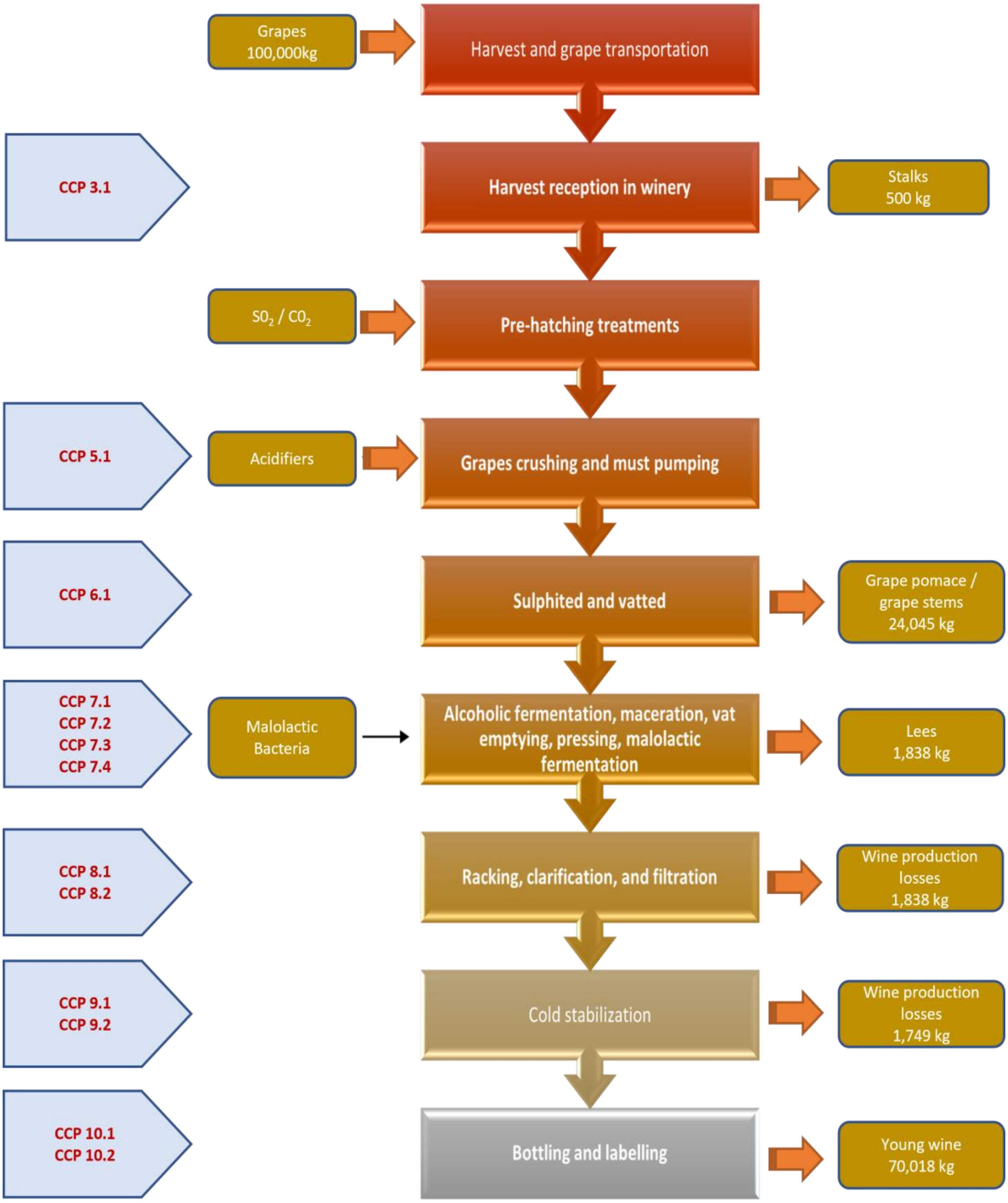

Figure 6. Flow diagram of the young wine making process and corresponding CCPs to each stage of this process. *Source:* Own elaboration based on (Bermúdez Leirós, 2020) and Table 5 of this work.

2.3 Environmental management

Over the past two decades, the European Union (EU) has increasingly prioritized environmental sustainability and commitment to the environment. In 2001, the EU integrated environmental issues into the Lisbon Strategy with the first European sustainable development strategy (Commission of the European Communities, 2001). Subsequently, in 2016, the EU incorporated the Sustainable Development Goals of the United Nations Agenda 2030 (United Nations General Assembly, 2015) through the communication titled "Next steps for a sustainable European future - European action for sustainability" (European Commission, 2016b).

To ensure effective implementation of environmental legislation in all member states, the EC established an instrument in May 2016 (European Commission, 2016a). In 2020, the EU strengthened its environmental commitment further with the 8th Multiannual Environment Action Programme from 2021 to 2030, which aims to "ensure well-being for all while respecting the limits of the planet" (European Union, 2022). Additionally, the environmental and climate objectives of the European Green Deal are supported by the 8th Multiannual Environmental Action Programme (European Commission, 2019b).

EM is based on a multi-level cyclical process in which different environmental managers interact with the environmental system components. These environmental managers actively manipulate the environment consciously, with the aim of improving its evolution in a socio-economic and environmental complex context. Environmental managers are state or non-state and interact with each other (Geoff A. Wilson & Raymond L. Bryant, 1997). Many authors showed that the implementation of EMS generates economic, operational, and environmental benefits for companies (Comoglio & Botta, 2012; Nishitani, 2011; Sambasivan & Fei, 2008). Nevertheless, other authors claimed that EMS do not allow a transformation in terms of sustainability (Blackman, 2012; Brown, 2016). Other research indicate EMS has been used to create economic value, cost savings and boost market share instead of achieving environmental improves (Horry, Booth, Mahamadu, Manu, &

Georgakis, 2022; Jones, S. & Laquidarra, 2018), or has been used as a marketing too (Turk, 2009).

EMS is a group of procedures, rules, and evidences that an organization establishes to minimize the environmental impacts produced in the development of its activity (Barla, 2007). These EMSs are used widely by many companies around the world (Marimon, Llach, & Bernardo, 2011; Neves, Salgado, & Beijo, 2017; To & Lee, 2014). EMS are often based on the standard ISO 14001:2015 (International Organization for Standardization, 2015) as a tool for initiative-taking EM (Salim et al., 2018a; Summers Raines, 2002). ISO 14001:2015 holds the necessary basic requirements that every EMS must follow with a focus on continuous and systematic improvement. It is used by organizations that look to enhance their environmental performance by complying with their environmental policy, objectives, and responsibilities. In this way, organizations contribute to strengthening the environmental pillar of sustainability (Technical Committee, 2015). EMS usually responds to ethical and competitive motivations from organizations boards (González-Benito & González-Benito, 2005). The EMS implementation results indicate a positive relationship between the environmental practices that a food company engages and its operations performance (Marimon, Llach, & Bernardo, 2011; Sroufe, 2003).

2.3.1 EM in wine production

Drawing on the detailed examinations by Hughey et al. (2005) and Flores (2018), the narrative delves into the varied landscape of EMS adoption within the wine industry, underscoring its broader implications for sustainability in agriculture. Hughey et al. (2005) present a nuanced comparison of EMS implementations, including Sustainable Winegrowing New Zealand (SWNZ), ISO 14001, and Bio-Gro, revealing how each system uniquely contributes to sustainability objectives. Their analysis not only underscores the tailored strengths of each system but also suggests that a hybrid approach, combining the specificity of industry-focused EMS with the robust process orientation of ISO 14001, could enhance sustainable practices across the wine sector.

Similarly, Flores (2018) expands on the significance of EMS, such as ISO 14001, in facilitating sustainable operations, emphasizing the growing consumer and market demands for sustainability within the wine industry. This study highlights the strategic advantage of sustainability practices, linking them to improved environmental outcomes and economic efficiency. The parallel drawn between the adoption of such systems in the wine industry and their potential application across broader agricultural practices suggests a pivotal role for EMS in navigating the sustainability challenges faced by the EU agriculture sector. These insights underscore the necessity of an integrated approach to sustainability, where EMS adoption is part of a comprehensive strategy to meet the environmental, economic, and social goals outlined in the European Green Deal and the Farm to Fork strategy.

Several research about wine industry show that as an agricultural sector is increasingly being challenged to reduce its environmental impact and enhance sustainability practices (Annunziata, Pucci, Frey, & Zanni, 2018; Jones, G. V. & Alves, 2012; Mozell & Thach, 2014).

2.3.2 EM through standard ISO 14001:2015

ISO 14001 is an internationally recognized voluntary standard that provides guidance on the establishment, implementation, and maintenance of EMS (Sartor, Orzes, Touboulic, Culot, & Nassimbeni, 2019; Zutshi & Sohal, 2004). Originally developed for the manufacturing and processing industries, ISO 14001 has since expanded its applicability to various sectors, including service industries with significant environmental impacts such as construction and transportation (Ahmed Aboulnaga, 1998; Pheng & Tan, 2005).

The primary objective of ISO 14001 is to assist organizations in managing their environmental responsibilities and improving their environmental performance. By adopting this standard, organizations can systematically identify and control their environmental aspects, set environmental objectives, and implement effective operational controls (Salim et al., 2018a).

ISO 14001 promotes an initiative-taking approach to EM, encouraging organizations to integrate environmental considerations into their overall business strategies (Ann, Zailani, & Abd Wahid, 2006). This standard emphasizes the importance of complying with environmental regulations and continuously improving environmental performance (Ahmed Aboulnaga, 1998).

Previous studies on EMS tools, like ISO 14001, have demonstrated their capacity to offer economic advantages to certified companies in the form of a competitive edge, alongside enhancing their environmental performance (Gilinsky Jr, Newton, & Vega, 2016). Research has shown several benefits associated with ISO 14001 implementation. For instance, organizations that have adopted ISO 14001 have reported improved environmental performance, reduced resource consumption, and enhanced finance performance practices (Leong et al., 2019; Melnyk, Sroufe, & Calantone, 2003; Montabon, Sroufe, & Narasimhan, 2007). ISO 14001 has also been linked to increased employee engagement, innovation, and positive relationships with stakeholders (Zhang, L., Ye, Yang, & Zhou, 2019).

Moreover, ISO 14001 helps organizations establish a systematic framework for identifying and managing environmental risks and opportunities. It also encourages organizations to engage in stakeholder communication and consultation, facilitating transparency and accountability in environmental matters (International Organization for Standardization, 2015).

ISO 14001 certification is widely recognized and can provide organizations with a competitive advantage in the marketplace. It demonstrates a commitment to environmental sustainability and can enhance the organization's reputation and credibility (Ann, Zailani, & Abd Wahid, 2006).

The ISO 14001:2015 standard consists of eight key components that provide a comprehensive framework for effective EM. These components outline the requirements and guidance for organizations seeking to establish and maintain an EMS aligned with ISO 14001:2015. **Table 6** shows main requirements of the ISO 14001:2015 standard. These components collectively provide a structured

Table 6. Main requirements of the 14001:2015 standard. *Source:* Own work, based on bibliography (International Organization for Standardization, 2015; International Organization for Standardization, 2015).

ISO 14001:2015 requirements	Concept
Scope	Applicability of the standard and specifies its requirements for organizations of all types and sizes, regardless of their environmental aspects or location.
Context of the Organization	Requires organizations to identify their internal and external context, including relevant interested parties and their needs and expectations. It also mandates the determination of the scope of the EMS and the establishment of the environmental policy.
Leadership	Role of top management in demonstrating leadership and commitment to the EMS. It includes requirements for establishing an environmental policy, assigning responsibilities, and ensuring the integration of EM into the organization's overall strategic direction.
Planning	Identification of environmental aspects and associated impacts, setting environmental objectives and targets, and establishing action plans to achieve them. It also addresses the need for risk assessment and contingency planning.
Support	Requirements for providing resources, competence, awareness, and communication to support the EMS implementation. It covers areas such as training, documentation control, and internal and external communication.
Operation	Execution of the planned activities and control measures, including operational planning and control, emergency preparedness and response, and the establishment of procedures for managing outsourced processes.
Performance Evaluation	Monitoring, measurement, analysis, and evaluation of the EMS performance. It includes requirements for conducting internal audits, evaluating compliance, and addressing nonconformities and corrective actions.
Improvement	Organization's commitment to continual improvement by taking corrective actions, implementing preventive measures, and considering opportunities for innovation and enhancing environmental performance.

approach for organizations to establish, implement, maintain, and continually improve their EMS based on ISO 14001:2015.

In response to these demands, wineries are turning to EMS such as ISO 14001:2015 to guide their efforts (De Steur, Temmerman, Gellynck, & Canavari, 2020; Falcó, Marco-Lajara, Sánchez-García, & Gilinsky Jr, 2023; Forbes & De Silva, 2012). ISO 14001:2015 provides wineries with a comprehensive framework for effective EM, encompassing practices ranging from vineyard management to packaging and distribution (Tahon & Batt, 2021).

ISO 14001:2015 offers wineries a structured approach to EM, comprising various key components. One essential aspect is the establishment of an environmental policy that outlines the winery's commitment to compliance with environmental regulations and continual improvement (International Organization for Standardization, 2015). This policy serves as a guiding document for setting environmental objectives and targets.

To ensure effective implementation, wineries must conduct a thorough assessment of their environmental aspects and impacts (Ardente, Beccali, Cellura, & Marvuglia, 2006). This involves identifying activities, products, and services that have significant environmental effects and evaluating their potential consequences on air and water quality, energy consumption, waste generation, and biodiversity.

Once the environmental aspects and impacts are determined, wineries can develop operational controls to mitigate risks and reduce environmental harm. Examples of these controls include implementing energy-efficient practices, adopting sustainable farming techniques, promoting water conservation measures, and utilizing eco-friendly packaging materials (Barber, 2010; Benni, Torreggiani, Barbaresi, & Tassinari, 2013; Matos & Pirra, 2020; Polanco, Sandoval, & Suárez, 2021; Schimmenti, Migliore, Di Franco, & Borsellino, 2016).

ISO 14001:2015 also emphasizes the importance of employee involvement and awareness in EM (Mariani & Vastola, 2015). Wineries are encouraged to provide training programs to enhance employees' understanding of environmental issues, their roles in achieving environmental objectives, and the significance of complying with environmental policies and procedures (Dodds, Graci, Ko, & Walker, 2013).

Furthermore, ISO 14001:2015 requires wineries to establish mechanisms for monitoring and measuring their environmental performance. This entails regular data collection, analysis, and reporting on key environmental indicators such as energy consumption, water usage, waste generation, and greenhouse gas emissions. By tracking their performance, wineries can identify areas for improvement and take corrective actions when necessary (Forbes & De Silva, 2012).

Effective communication and engagement with stakeholders are also integral to ISO 14001:2015 implementation. Wineries are encouraged to involve suppliers, customers, and local communities in their EM efforts, fostering partnerships and promoting transparency (International Organization for Standardization, 2015).

ISO 14001:2015 places a strong emphasis on continual improvement. Wineries are expected to regularly review their environmental performance, assess their progress towards achieving objectives, and identify opportunities for further enhancement. This iterative process ensures that wineries are consistently striving for improved environmental outcomes (International Organization for Standardization, 2015).

The benefits of ISO 14001:2015 implementation extend beyond environmental performance. It can also have positive economic impacts for wineries. Studies have shown that ISO 14001 certification can enhance market access, increase competitiveness, and improve financial performance (Gilinsky Jr, Newton, & Vega, 2016).

2.4 Prior research

A collection of studies relevant to the research focus of this thesis were meticulously analysed and compared to ensure a thorough understanding of the existing body of knowledge. **Annex A** contains a detailed summary of each article, providing a clear overview of the key findings and methodologies employed. Additionally, **Table 7** offers a comparative analysis of these studies, systematically highlighting similarities and differences to better elucidate the context and implications of prior research in relation to the current thesis. This structured comparison not only enhances the comprehension of the field but also strategically informs the research direction taken in this thesis.

The synthesis of the literature on sustainability within the WSC reveals a complex and multifaceted discourse that spans across strategic adoption, competitive advantages, the implementation of EMS, the criticality of performance measurement, and the nuanced integration of FS practices with overarching sustainability goals. This expansive narrative underscores the necessity for a comprehensive approach to sustainability that is tailored, measurable, and responsive to the unique challenges and opportunities within the wine industry.

2.4.1 Strategic Adoption and Sector-Wide Challenges

The literature highlights a systemic challenge in the strategic adoption of sustainability principles across the wine industry. Epuran et al. (2018) provide a case study within Romania's wine sector that exemplifies broader issues facing the wine value chain, where legislative complexities and technological adoption barriers necessitate more innovative and effective sustainability strategies. This discussion opens a broader conversation about the need for sector-wide initiatives that are not only adaptive to legislative frameworks but also embrace technological advancements to foster sustainability.

Table 7. Comparative analysis of prior research

Authors	Main Objectives	Location	Methods	Main findings
Epuran, G. et al., (2018)	Prove the implementation of sustainable development practices and strategies in the wine industry as wine industry's sustainable marketing, tech challenges, link FS, and wine quality with culture while understanding manager willingness.	Romania	Qualitative marketing techniques through interviews, examination of sustainability principles, and analysis of technology usage and marketing strategies.	• Limited strategic adoption of sustainability principles in the wine industry. • Bio certifications face cost limitations. • Eco-labeling is not strongly associated with sustainability by consumers. • Challenges in adopting modern tech due to burdensome European legislation. • Varied marketing strategies employed. • Emphasis on cultural and educational context for wine consumption. • Compliance with environmental regulations poses obstacles to eco-friendly wine production.
Gilinsky Jr, A., et al., (2016).	Explore the relationship between sustainability and the wine industry, promoting environmental stewardship, and assessing sustainable strategies. Develop metrics, benchmark sustainability, analyse wine businesses, and provide practical insights through case studies on sustainability practices.	New Zealand, United States of America, and Spain	Qualitative analysis of sustainability practices, examination of case studies, and emphasis on EMS implementation.	• Sustainable practices offer a competitive advantage and enhance business performance in the wine industry. • Incumbent businesses may resist sustainability due to concerns about product line cannibalization. • Younger and entrepreneurial wine businesses are more inclined to invest in sustainability. • A sustainable wine business aims to balance environmental and social impact while maintaining financial viability. • A triple-bottom-line strategy for sustainability includes social, environmental, and financial stewardship. • The research contributes to a broader understanding of sustainability in the wine industry and provides practical insights. • Case studies reveal diverse regional approaches and challenges in achieving sustainability among wineries. • Sustainable wine businesses are emerging on a global scale, highlighting the importance of EMS.

Authors	Main Objectives	Location	Methods	Main findings
Flores, S.S. (2018).	Emphasize the significance of sustainability in the wine industry and highlight the role of EMS like ISO 14001 in promoting sustainability. Recognize and assess customer demand, benefits, and preferences for sustainability in the wine industry. Examine and categorize official, regional, and common trends in sustainability frameworks, emphasizing context-specific initiatives and encouraging further research.	Australia, Chile, France, New Zealand, South Africa, and United States of America.	Cross-country qualitative study that involves a literature review, document search, and expert consultations in two phases: (1) selecting key countries/regions in wine sustainability, and (2) analysing sustainability frameworks.	• Sustainability is crucial in the wine industry due to customer demand and the potential for competitive advantage. • EMS like ISO 14001 play a role in promoting sustainability. • Customers value sustainable wine practices and are willing to pay more for sustainable products. • Producers benefit from sustainability in terms of environmental improvement and economic efficiency. • Sustainability frameworks encompass environmental, social, economic, and cultural aspects. • Several types of sustainability frameworks exist to support decision-making and continuous improvement. • A qualitative study analysed sustainability frameworks, identifying common trends and characteristics. • Context-specific sustainability initiatives are vital, and further research is needed to enhance sustainability in the wine industry.
Hughey, K. F. et al. (2005)	Conduct a comprehensive comparative evaluation of three EMS (EMS) in the New Zealand wine industry (SWNZ, ISO 14001, and Bio-Gro) and assess their sustainability, implementation, and marketing performance. Emphasize the importance of considering economic, environmental, and social factors in evaluating EMS while providing insights for policymakers and businesses to promote sustainability in the industry.	New Zealand	Qualitative interviews with fifteen New Zealand vineyards, including Bio-Gro, ISO 14001, and SWNZ-accredited ones	• Each EMS system (SWNZ, ISO 14001, Bio-Gro) has its unique strengths, and there is no clear superiority among them. • Combining an industry-specific system like SWNZ with a generic process-based system like ISO 14001 contributes to a more sustainable wine industry. • Consideration of economic, environmental, and social factors, as well as the industry's specific characteristics, is crucial when evaluating EMS performance. • Identifying unsustainable practices and setting short-term sustainability goals is essential for long-term sustainability. • Challenges and criticisms related to EMS implementation and effectiveness were addressed, including the lack of eco-labelling for SWNZ-accredited companies and confidentiality issues with ISO 14001. • A survey revealed varying levels of improvement in environmental and social effectiveness, business implications, system issues, and sustainability among different certification systems. • Reasons for choosing specific EMS varied, with SWNZ selected for its progressive nature, ISO 14001 for its flexibility, and Bio-Gro for its compatibility with sustainability principles. • Integration of EMS systems with Triple Bottom Line reporting can enhance sustainability promotion in the wine industry.

Authors	Main Objectives	Location	Methods	Main findings
Tahon, C. et al. (2021)	Examine and assess the environmental and social sustainability practices within the Bordeaux wine value chain, including soil management, energy reduction, and sustainable sourcing. Imply the potential use of EMS in formalizing and guiding sustainability practices and highlight the importance of shorter distribution chains in achieving sustainability goals.	France	Research review	• Environmental sustainability practices are more established and widely adopted within the WVC compared to social sustainability practices. • Wine grape growers focus on environmentally sustainable practices, including soil management, reduced use of phytosanitary products, water management, biodiversity preservation, and CO_2 emissions reduction. Techniques like adding organic matter to soil and integrated pest control are employed. • Wineries prioritize reducing energy consumption through LED lighting, solar panels, and improved wine tank cooling. Sustainable water management, packaging, and shorter distribution chains are also important. • The study implies the potential use of EMS in guiding and formalizing sustainability practices. • Shorter distribution chains are identified as vital for reducing CO_2 emissions and enhancing pricing control, aligning with sustainable supply chain management concepts. • Distributors express interest in nonconventional agricultural practices and prefer wines adhering to biodynamic or organic agriculture principles, suggesting a potential role for EMS in supplier selection for sustainable sourcing

Authors	Main Objectives	Location	Methods	Main findings
Vågsholm, I., Arzoomand, N. S., & Boqvist, S. (2020)	Establish a seamless integration between FS practices and sustainability goals within the global food supply chain, developing strategies that ensure the safety of food products without compromising sustainability, particularly by reducing food waste, responsible antimicrobial use, and adopting circular food production systems. Make informed decisions regarding FS, food security, and sustainability by prioritizing evidence-based trade-offs. This includes advancing research and innovation to achieve food security without relying on antimicrobials, transitioning towards sustainable and resilient agricultural practices, and leveraging modern technology for efficient source reduction, reprocessing, and recycling of food while considering economic, social, and environmental sustainability factors.	Global	Research review	• Interconnectedness of FS, food security, and sustainability in achieving global development goals. • Approximately one-third of global food production is lost or wasted, resulting in significant economic, environmental, and social costs. • Circular food production systems show promise in reducing waste and environmental impact but introduce new risks related to FS and disease control. • Strategies for recovering energy and nutrients from food waste are discussed, with a focus on their implications for sustainability, food security, and FS. • Sustainable agriculture and aquaculture should operate within environmental boundaries, considering ecological, resource, social, and food security dimensions. • Unsustainable use of antimicrobials in food production, contributing to AMR and public health risks. • Efforts to redistribute and reprocess food are explored, including concerns about FS as donated food approaches its expiration date. • Biofuel production is considered but raises concerns about diverting edible crops into biofuels, impacting food security and social sustainability. • Various waste disposal methods, including incineration and landfills, are discussed, each with its environmental and FS implications. • Shifting towards more plant-based diets is suggested to reduce food waste and enhance sustainability, aligning with global recommendations. • Importance of making evidence-based trade-offs between FS, food security, and sustainability to address the complex challenges of global food systems effectively. • Modern IT technology is highlighted as promising for achieving more efficient source reduction, reprocessing, and recycling of food, contributing to food security and sustainability. • The transition from intensive cereal-based farming to extensive pastoral farming implies changes to veterinary medicine, with a focus on issues such as nutritional supplements and disease control. • Trade-offs and decisions regarding FS, food security, and sustainability should be evidence-based to ensure success in addressing global food challenges.

2.4.2 Competitive dynamics and adoption barriers

Gilinsky Jr. et al. (2016) delve into the nuanced dynamics of sustainability as both a source of competitive advantage and a potential barrier to adoption within the wine industry. The variance in sustainability adoption between established businesses and emergent, entrepreneurial entities highlights a critical gap. This dichotomy calls for tailored strategies that address the concerns of legacy businesses while leveraging the agility and innovation propensity of newer entrants, aiming to foster a more cohesive sector-wide adoption of sustainable practices.

2.4.3 EMS as a catalyst for sustainability practices

The role of EMS, notably ISO 14001, as pivotal in promoting sustainability within the wine industry, is a recurring theme. Flores (2018) underscores the growing consumer demand for sustainable wine practices, advocating for structured and quantifiable sustainability approaches. This perspective is echoed by Hughey et al. (2005) and Tahon et al. (2021), who explore the varied strengths and potential of EMS implementations across different contexts within the wine industry. Their findings point to the opportunity for advancing sustainability through more robust performance measurement and assessment methodologies, enhancing the effectiveness of EMS in guiding sustainable practices.

2.4.4 Enhancing sustainability through performance measurement

The literature consistently identifies the critical role of performance measurement in elevating the sustainability agenda within the wine industry. The diversity in the effectiveness of existing EMS and the detailed exploration of these systems' strengths and weaknesses underscore a significant opportunity for the industry. Developing and implementing comprehensive performance metrics can facilitate a deeper understanding of sustainability practices, pinpoint areas for improvement, and drive the evolution of more impactful sustainability strategies.

2.4.5 Integrating FS and sustainable practices

Expanding the scope of discussion, Vågsholm et al. (2020) emphasize the intricate relationship between FS practices and sustainability goals, particularly within the ASC.

Their advocacy for evidence-based decision-making in marrying FS with sustainability objectives highlights the complex interplay between ensuring food safety and pursuing environmental, economic, and social sustainability. This convergence necessitates a nuanced approach that aligns FS measures with sustainability targets, reinforcing the imperative for a comprehensive and integrated strategy.

The synthesis elucidates the necessity for a multi-dimensional approach to sustainability in the wine industry that transcends environmental considerations to encompass economic viability and social equity. The literature advocates for the strategic adoption of EMS and performance measurement as fundamental components of this approach, facilitating a more nuanced and effective integration of sustainable practices. Moreover, it calls for an industry-wide shift in mindset—from viewing sustainability as a regulatory compliance or competitive strategy to embracing it as a core ethos that guides all facets of operation. This shift is crucial for addressing the varied challenges highlighted across the literature, from legislative and technological hurdles to the barriers to adoption and the integration of FS into the sustainability framework. This comprehensive synthesis not only reflects the collective insights from the literature but also charts a path forward for achieving a more sustainable, equitable, and resilient wine industry.

2.5 Research Questions, Hypothesis and Objectives

2.5.1 Research Questions (RQs) emerging from the Literature Review

The comprehensive review of literature concerning on the performance of FS and EMS in advancing sustainability in wine production has led to the formulation of several pertinent RQs. These questions are designed to address the gaps identified in current knowledge and aim to deepen the understanding of how FS and EM practices can be effectively integrated and enhanced to promote sustainability in wine production. These RQs set the stage for further exploration and analysis in the subsequent chapters of this thesis.

- **RQ.01.-Can we measure progress towards sustainability using FS an EM tools in wine production?**
- **RQ.02.-What are the critical factors and performance indicators of FS tools that can be used as proxy to measure towards sustainability in wine production?**
- **RQ.03.-What are the critical factors and performance indicators of EM tools that can be used as proxy to measure towards sustainability in wine production?**
- **RQ.04.-How can we measure progress towards sustainability based on FS an EM tools performance?**

2.5.2 Hypothesis

1.1.1 Hypothesis

The central hypothesis of this thesis is that **the progress towards sustainability of wine production is related with the implementation level of FSMS and EMS based on HACCP and ISO 14001:2015 standards in wineries**.

This hypothesis suggests that by ensuring an adequate performance level of food safety and environmental management in wineries according to established standards, contribute to the progress in sustainability of the wine supply chain.

This hypothesis is examined by assessing the extent of FSMS and EMS adoption in wineries with different annual wine production volumes and from two countries. These include assessing key topics regarding to mitigate health risks for wine consumers, minimize environmental impacts stemming from wine production, demonstrate a commitment to environmental stewardship, monitor compliance with FS and environmental legislation, and explicit leadership from top management in fostering sustainability practices.

2.5.3 Objectives

2.5.3.1 General Objective

The primary objective is **to propose a measure of the progress towards sustainability in wineries based on specific management tools**. This objective sets the stage for a better understanding of sustainability components within the sector that can contribute to promote more sustainable practices.

2.5.3.2 Specific Objectives

SO-1.- Analyse and evaluate the FS management in promoting the sustainability of the wine production.

SO-2.- Analyse and evaluate the EM performance in promoting the sustainability of the wine production.

SO-3.- Identify and analyse key components of sustainability in the wineries based on FS management and EM.

SO-4.- Design a tool to measure progress of sustainability and test it.

3 Methods

3.1 Thesis Methodology

The methodology consists in a systematic approach to address the stated problem and achieve the outlined hypothesis and objectives. The methodology is depicted in Figure 7, which delineates a comprehensive approach tailored to analyse the FS and EM in wineries as tools towards the sustainability in the wine production.

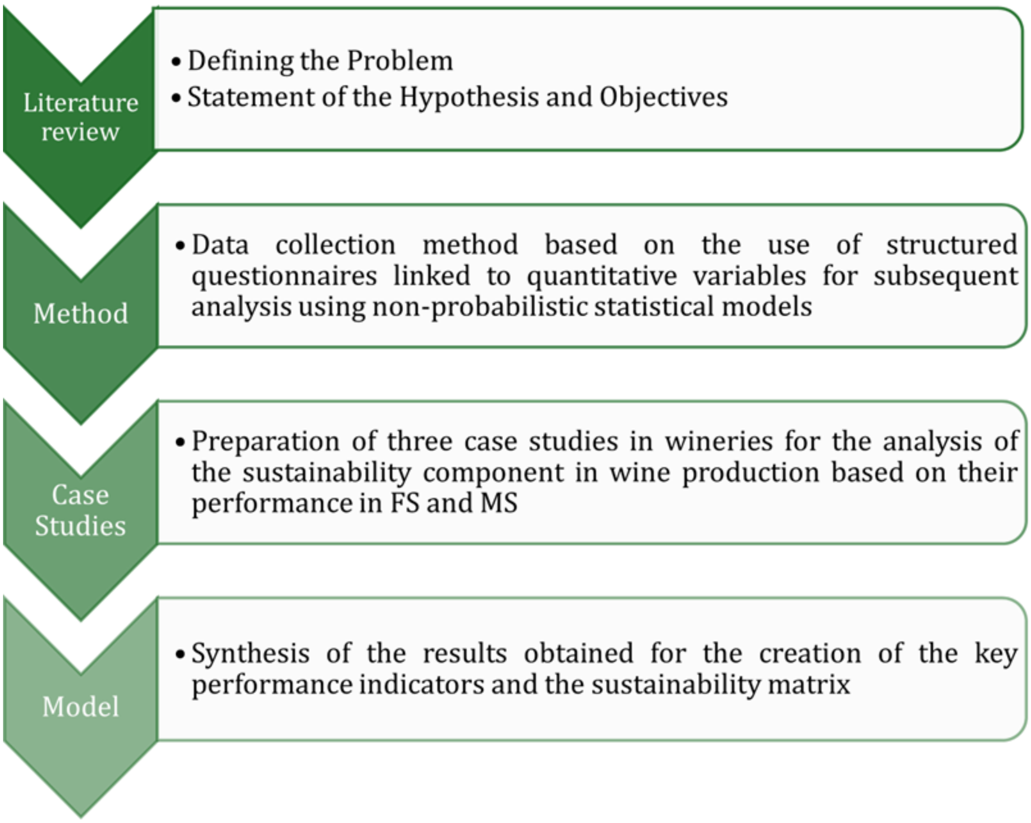

Figure 7. Thesis methodology

3.1.1 Literature Review

The methodology commences with an extensive literature review, aiming to build a solid foundation for the study by synthesizing existing research. This crucial step involves a thorough examination of scholarly articles, books, and other academic sources relevant to wine production, agrifood and wine sustainability, FS and EM concepts and their application in wineries. The literature review serves multiple purposes: it identifies gaps in current knowledge, informs the research questions and hypotheses, and justifies the relevance of the study.

3.1.2 Defining the Problem Statement, Hypothesis, and Objectives

Following the literature review, the methodology involves articulating a clear problem statement, formulating hypothesis, and setting precise research objectives. The problem statement defines the issue that the research intends to address, rooted in the gaps identified during the literature review. The hypothesis posits a potential answer or solution to the problem statement, which the research will test. Objectives outline the specific goals the study aims to achieve, guiding the research process towards its ultimate purpose.

3.1.3 Method

Central to this method is the data collection, which relies on structured questionnaires linked to quantitative variables. This approach facilitates the gathering of measurable, objective data that can be analysed through non-probabilistic statistical models. The choice of structured questionnaires ensures a standardized method of data collection, allowing for the consistent gathering of information across different subjects or cases. The emphasis on quantitative variables aligns with the study objectives to produce statistically valid and generalizable findings.

3.1.4 Case Studies

A distinctive feature of this methodology is the preparation of three case studies in wineries, chosen for their relevance to the research questions and objectives. These case studies offer an in-depth analysis of the sustainability component in wine production, examining each winery performance in FS and EM. By focusing on specific instances, the research can uncover nuanced insights into how sustainability practices are implemented in real-world settings, providing a rich source of data that complements the quantitative analysis.

3.1.5 Wineries performance assessment tool

The culmination of the methodology is the synthesis of the results obtained from both the questionnaires and the case studies. This synthesis involves the creation of performance indicators and a sustainability matrix (SM). The performance indicators are quantifiable measures that reflect the wineries performance in terms of sustainable practices, specifically in FS and EM aspects. The SM, on the other hand, provides a tool for evaluating and comparing the progress towards sustainability of the wineries. This SM aims to offer a comprehensive tool for assessing the progress towards sustainability in wine production, contributing valuable insights to both academia and industry.

In summary, the methodology of the thesis adopts a multifaceted approach to propose a measure of the progress towards sustainability in wineries based on specific management tools. in wine production. By integrating a structured questionnaire, detailed case studies, and the development of a comprehensive tool, the research strives to provide a comprehensive understanding of sustainability practices within the wine industry, with the potential to inform future practices and policies.

3.2 Method used to establish the research case studies.

The empiric method employed to establish the research case studies was structured as a four-step process. Wherein each step was devoted to assessing the efficacy of wineries in the deployment of FSMS and EMS. The initial three steps were aligned with the investigation of three distinct case studies. Insights derived from each evaluative step informed subsequent research efforts, aimed at devising a metric for quantifying the sustainability of wineries. This metric was based on how well the wineries managed FS and EM practices. **Figure 8** shows the evolution of this methodological approach, inclusive of the interconnections among the steps and their congruence with the theoretical framework. The outcomes of the first case study facilitated the identification of CCPs that were inadequately managed by the wineries and the principal components that support the wineries performance in FS management. Leveraging these findings, the second case study delineated performance indicators for the components identified in the first step. The third case study delved into the EM practices by examining the EMS components based on ISO 14001:2015 standard and employed the proposed methodology to compute the indicators from the second step to formulate performance indicators in EM. The four-step involved synthesizing the three investigations to develop a FS and EM sustainability matrix based on performance indicators calculated from the results of case studies two and three.

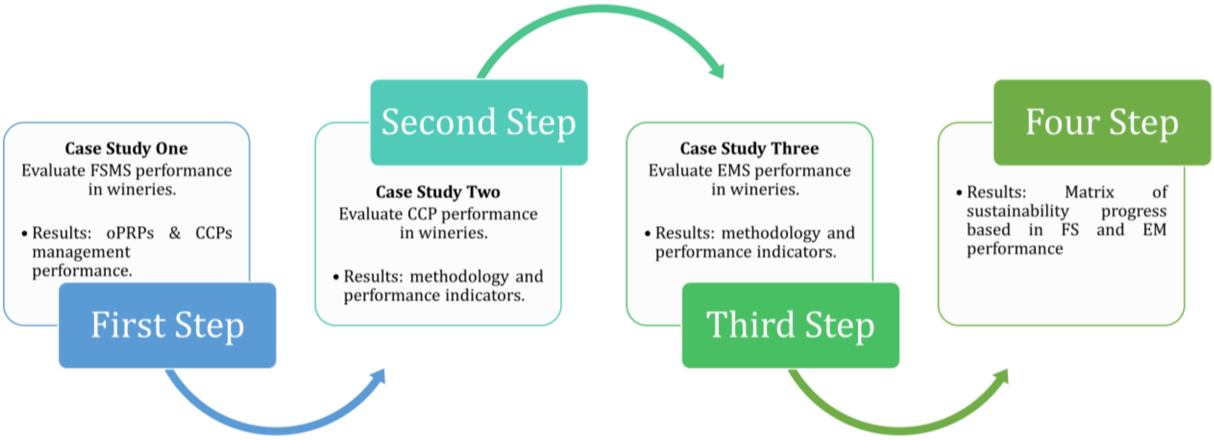

Figure 8. Flow diagram of the case studies process.

3.2.1 First Step: Evaluation of FS performance in wineries as a component towards sustainability in wine production.

A case study was conducted to evaluate the effectiveness of the FSMS performance in wineries. This preliminary research serves as the foundation for **specific objective 1 (SO-1)** which aims to analyse and evaluate how FS performance practices to promote sustainability within wine production. A survey-based methodology was employed to evaluate the performance of the FSMS in wineries, with a specific emphasis on implementing PRPs and HACCP system. The research specifically focused on wineries within the Protected Designation of Origin (PDO) "Vinos de Madrid," a designation chosen from an autonomous community to select the sample and start the investigation analysing their control over CCPs throughout the winemaking process. The research spanned the final quarter of 2021 and involved statistical analysis using IBM SPSS Statistics. Descriptive statistics, nonparametric measures like the Spearman correlation coefficient (ρ), the Kruskal-Wallis test, and contingency tables were utilized for in-depth analysis.

A non-probabilistic sampling method was employed, based on the researcher's prior information, resulting in a sample size of twenty-one wineries out of a total population of fifty-one under PDO "Vinos de Madrid." The survey, conducted through email and telephone contact. The subsequent survey, consisting of fifty-five questions across eleven sections, aimed to evaluate PRPs and HACCP programs' performance.

The first section focused on annual red wine production and PRPs implementation, assessing winery size and various aspects related to PRPs. Sections two to ten concentrated on HACCP Principles 1 and 2, encompassing thirty-seven items related to hazard analysis and determination of CCPs at various stages of red wine production. A Likert scale coding approach was used for qualitative responses, providing a numerical scale for analysis. High variability was determined when the interquartile range value equalled or exceeded two.

Section eleven centred on the practical implementation of HACCP Principles 3 to 7, with dichotomous and multiple-choice questions assessing critical limits, surveillance systems, corrective measures, verification procedures, and the system of registration and documentation. Overall, the methodology facilitated a detailed examination of PRPs and HACCP implementation in wineries, emphasizing both quantitative and qualitative aspects of their FSM.

3.2.2 Second Step: Establishment of FS performance indicators by evaluating the key wineries performance components in their CCPs control.

This study introduces a survey-based methodology designed to evaluate sustainable practices in wineries, focusing specifically on their management of CCPs within the FSMS. This assessment forms the basis for **specific objective 3 (SO-3),** which aims to identify and analyse key components of sustainability in wineries, anchored in FS performance The focus is specifically on assessing the performance of CCPs related to the contamination risk posed by arsenic, cadmium, and lead, identified as inadequately controlled points. The methodology involves a questionnaire with sixteen questions utilizing a Likert Scale for quantitative variables, assessing training, legislation, and analysis components. The study expanded beyond a single Wine Protected Designation of Origins (WPDO), encompassing all denominations of origin across Spain, to broaden the scope of the research and enhance its comprehensiveness. This expanded focus allows for a more thorough and representative analysis of the sustainability practices in wineries and their management of FS risks nationwide.

The study was conducted in the latter half of 2022 in various Spanish wine regions, and it employed statistical methods, including descriptive statistics and non-parametric tests like Spearman correlation coefficient and Kendall's Tau coefficient. The sample consisted of 139 wineries selected from different WPDO, using a non-probabilistic sampling method based on previous information.

The survey was distributed twice over two months, and it focused on wineries' knowledge of and adherence to national legislation regarding arsenic, cadmium, and lead contamination risks. It also explored information available to wineries regarding vineyard soil conditions, fertilizer usage, and chemical analysis of soils. Questions delved into wineries' procedures and resources for chemical analysis in grapes and wines, including the use of external laboratories and the possession of spectrometry equipment.

The questionnaire was organized into five sections that covered winery characteristics, implementation of PRPs and HACCP, worker training, legislation awareness, soil and chemical analysis information, and resources for chemical analysis. The study involved thirty-two responding wineries, representing 23% of the sampled wineries, and aimed to provide a comprehensive assessment of wineries' management of CCPs related to arsenic, cadmium, and lead contamination risks in the winemaking process.

3.2.3 Third Step: Evaluation of EM performance in wineries and establishment of performance indicators by evaluating their EMS based on ISO 14001:2015.

The study employs a survey-based research design to evaluate the EMS performance in Italian wineries, with the survey being conducted from June to November 2022. Targeting 120 wineries across various Italian wine regions, this comprehensive assessment underpins **specific objective 2 (SO-2)**, which is to analyse and evaluate the effectiveness of EM practices in promoting sustainability within the wine production. Additionally, the case study is crucial for achieving **specific objective 3 (SO-3)**, which involves identifying and analysing key sustainability components in wineries, particularly those related to EM performance. The selection of wineries in Italy was strategic, given that the country is recognized as the European nation with the most extensive implementation of EMS, particularly those based on ISO 14001:2015 standards (Enhesa, 2024). This focus not only allows for a comprehensive evaluation of EMS performance within a leading wine-producing country but also offers insights into the adherence to and effectiveness of international EM standards within the viticultural sector.

Data analysis involved SPSS Windows software and Excel with calculated statistics including frequencies, central position values, and non-parametric tests such as Spearman correlation coefficient and Kendall's Tau coefficient.

The Italian wine industry unique characteristics, marked by high segmentation and duality, were considered in the sample selection. The non-probabilistic method was employed, utilizing prior information for selection rather than randomization. A total of thirty-four wineries responded to the questionnaire out of the one hundred and twenty surveyed.

The survey questionnaire was structured with thirty-two questions divided into twelve sections and it was designed based on ISO 14001:2015 content and previous research studies. Closed-ended questions, Likert scales, and open-ended questions were used to gather information on various aspects of wineries' EM, including communication strategies, environmental objectives, top management commitment, formulation of environmental policies, key environmental aspects in winemaking, emergency plans, document control, workers' training, legal compliance, and risk/opportunity assessment. The questionnaire aimed to evaluate wineries' effectiveness in managing environmental performance and adherence to ISO 14001:2015 standards.

3.2.4 Fourth Step: Wineries performance assessment tool: Sustainability Matrix

The fourth step of the research process synthesizes findings from the first three phases, achieving **specific objective 4 (SO-4)** by developing a Sustainability Matrix (SM) specifically for wineries. This matrix serves as a practical tool to measure and track wineries sustainability progress. This matrix stands as a pivotal achievement in the thesis, leveraging key performance indicators meticulously calculated from the data amassed in the previous steps. Each indicator within the matrix has been strategically developed to encapsulate key aspects of sustainability in the winemaking process, focusing on critical parameters that reflect the wineries compliance with FS and EM.

Through the integration of diverse data sets, spanning FSMS and EMS, the matrix offers a robust framework for assessing and benchmarking sustainable practices performance across wineries. It captures not only the adherence to predefined safety and environmental protocols but also the effectiveness of implemented practices in mitigating risks and enhancing sustainable operations.

4 Results

4.1 Article one

López-Santiago, J., García, A. I. G., & Gómez-Villarino, M. T. (2022). **An Evaluation of Food Safety Performance in Wineries**. Foods, 11(9), 1249

The study addresses the **specific objective (SO-1)**., which is to analyse and evaluate the FS management in promoting the sustainability of the wine production, by examining the enforcement of hygiene legislation and the application of the HACCP methodological framework.

The examination of wineries based on their annual wine production underscores the significance of implementing PRPs as a pivotal facet of EM. The wineries are classified into four groups, with the highest production group (annual wine production greater than 500,000 L/year) not yielding responses. The study discloses that a substantial 91.5% of wineries have successfully implemented PRPs, delineating the percentage of wineries that have incorporated specific programs within the standard PRPs.

In terms of FS worker training, the analysis reveals that 81% of wineries have a workforce where at least 50% are trained in GMP in winemaking, with a noteworthy concentration in wineries exceeding 100,000 L/year. Concerning PRPs knowledge, 95% of wineries report that over 50% of their workforce possesses adequate knowledge, highlighting variations based on annual wine production.

The economic perspective uncovers that 62% of wineries formulate their PRPs plans without a specific annual budget. In contrast, 40% of wineries with an annual production ranging between 100,001 and 250,000 L/year, and 100% of those exceeding 250,000 L/year, maintain a dedicated budget. This underscores a substantive correlation between winery size and the presence of a specified annual budget for PRPs development.

A comprehensive exploration of HACCP implementation in wineries is conducted, encompassing the overall implementation rate, performance in principles one and two, and a meticulous examination of specific control points. The study discloses that 76.2% of wineries have embraced HACCP, with variations contingent on annual production levels. CCPs are categorized into five groups based on median values and variability, portraying the extent of control over each CCP, ranging from "Never" controlled to "Always" controlled.

Moreover, the performance analysis of CCPs highlights varying degrees of control over specific winemaking steps, underscoring the pivotal role of well-controlled CCPs in ensuring the safety of the final product. Correlations between different CCPs are explored, revealing associations between safety and purity control of additives, control of residue from wine clarifiers, and other key variables. The text delves into the impact of annual wine production on CCP control, with most variables showing no significant differences based on production levels, except for VAR6.1.

This study delivers a detailed and nuanced analysis of HACCP implementation and control performance in wineries, shedding light on specific critical points that necessitate heightened attention to guarantee the safety and quality of the final wine product. The subsequent focus on the practical implementation of HACCP Principles three to seven reveals variations across different production levels, emphasizing key aspects such as the adoption of critical limits, surveillance systems, corrective measures, verification procedures, and registration/documentation systems. The findings underscore the diversity in HACCP system documentation among wineries, with an insightful breakdown of the inclusion of diverse types of documents. Overall, the text provides a comprehensive understanding of the practical application of HACCP principles, recognizing the pivotal role they play in ensuring FS within winemaking processes.

The findings offer insightful responses to the RQs about the metrics that most effectively quantify the performance of FSMS, in promoting sustainable practices within winemaking. Additionally, the results shed light on which specific practices and compliance measures within FSMS are most reflective towards wineries sustainable winemaking practices. Furthermore, this case study explores how these practices contribute to broader sustainability within the wine production, providing a deeper understanding of the critical elements that drive sustainable advancements in the industry. The study demonstrates that the methodology employed becomes an appropriate tool for measuring the performance of wineries in implementing their FSMS. Factors such as worker training, the correct application of HACCP principles, and fundamentally, the proper control of CCPs explain the adequate performance in the implementation of FSMS in the winery.

foods

Article

An Evaluation of Food Safety Performance in Wineries

Jesús López-Santiago *, Ana Isabel García García and María Teresa Gómez-Villarino

Agroforestry Engineering Department, School of Agricultural, Food and Biosystems Engineering, Universidad Politécnica de Madrid, 28040 Madrid, Spain; ai.garcia@upm.es (A.I.G.G.); teresa.gomez.villarino@upm.es (M.T.G.-V.)
* Correspondence: jesus.lopez.santiago@upm.es; Tel.: +34-913-365-837

Abstract: Wine production has food safety hazards. A Hazard Analysis Critical Control Point (HACCP) system makes it possible to identify, evaluate, and control significant food safety hazards throughout the wine production process. The Prerequisites Programs (PPRs) and HACCP performance in Protected Denomination of Origin "Vinos de Madrid" wineries were analyzed. Winery performances were evaluated for every critical control point (CCPs) in each winemaking process stage, including their implementation of PPR and HACCP principles. This study was developed through a survey of 55 questions divided into 11 sections, and it was conducted on a sample of 21 wineries. The results revealed that the CCPs worst performance level are for the control of metals (Cd, Pb, As) in grapes and fungicides or pesticide control in the harvest reception. A total of 91.5% of the wineries had implemented a prerequisites program (PPRs), regardless of their annual wine production. However, there was variability in the type of prerequisite plans, training, level of knowledge of operators, and annual budget allocation. Three out of four wineries had an HACCP, although corrective action procedures and verification procedures had the lowest and the worst HACCP practical implementation. The significant barriers for HACCP performance in wineries are linked with a lack of food safety staff training, low involvement of all staff in food safety tasks, and poor application of CCP chemical and microbiologic control methods.

Keywords: beverages; HACCP; food hazards; food safety; wine; wineries

check for updates

Citation: López-Santiago, J.; García, A.I.G.; Gómez-Villarino, M.T. An Evaluation of Food Safety Performance in Wineries. *Foods* **2022**, *11*, 1249. https://doi.org/10.3390/foods11091249

Academic Editors: Antonietta Baiano and Pasquale Massimiliano Falcone

Received: 30 March 2022
Accepted: 24 April 2022
Published: 26 April 2022

1. Introduction

Wine is an alcoholic beverage that results from the fermentation of grapes. The winemaking process follows appropriate steps along with the addition of certain additives, such as sulfur dioxide, tartaric acid, or egg albumin [1]. The wines are manufactured using a common generic process but with some variations depending on the type of wine that is being produced. In the European Union, these oenological practices are regulated by EC Regulations n° 423/2008, n° 479/2008, and n° 606/2009 [2–4].

The process of making red wine begins when grapes are harvested and transported to the winery. Grapes are crushed and stemmed, obtaining a semi-liquid composed of skins, seeds, pulp, musts, and scrapes. Subsequently, it receives corrections such as the addition of sulfur dioxide to obtain an antioxidant and an antiseptic effect. All these additives are regulated in the European Union by EC Regulations n° 1333/2008, n° 1129/2011, and n° 1130/2011 [5–7].

Alcoholic fermentation takes place in large vats, and it is triggered by yeasts when sugars are converted in ethanol [8]. Maceration and fermentation processes occur simultaneously [9,10]. The liquid part of the grape is also called must-wine. Must-wine is transformed by fermentation. At the same time, must-wine exchanges components with the solid parts of the grapes. The extraction of anthocyanins from the skins is of major interest because they are responsible for providing the final red color of wines [11–13]. Alcoholic fermentation takes from 10 to 20 days, depending on the temperature [14].

Vat is drawing off and the malolactic fermentation starts to transform malic acid into lactic acid by lactic bacteria [15]. Malolactic fermentation achieves the lasting stabilization of the wine, preventing the development of other types of bacteria [16]. Particles, such as yeasts, solids, or other organic matter, are decanted and deposited at the bottom of the vat. All these particles are known as "wine waste".

Racking avoids any contact between the wine and the "wine waste", which can cause losses in the organoleptic properties of the wine. Suspended particles are removed by adding clarifying or colloidal substances, such as egg albumin, gelatin, or alginate [17–19].

Wine is filtered through a porous material to retain possible solid particles that remain in the liquid phase eliminating turbid or precipitated wines [20].

Wine is stabilized chemically and biologically by cold keeping wine stable in the long term [17]. This stage inhibits microbial growth, and it avoids oxidative reactions. Finally, wine is bottled to protect it from external agents that deteriorate it.

During all of the above processes, the characteristic flavor and aroma of wines are formed [21,22]. However, grapes, must, and wines are susceptible to several safety hazards. These food safety risks include physical (metal parts, glass, insects), chemical (pesticide residues, heavy metal residues, urea), and microbiological (pathogens) hazards affecting the health of consumers [23].

Hazards that appear in wine production may come from the environment, processing equipment, and workers of the winery. Nevertheless, the two common causes of major food safety incidents are those related to undeclared allergens and cross-contamination [24]. Hygienic conditions and practices are required to prevent the introduction of hazardous agents. In winemaking, the main hazardous agents are the increase in the microbiological load or the accumulation of residues and other chemical and/or physical agents produced directly and indirectly.

According to European food law, "Food shall be deemed to be unsafe if it is injurious to health or unfit for human consumption" [25]. Food security occurs when "all people have permanent physical, social, and economic access to safe, nutritious food in sufficient quantity to meet their nutritional requirements and food preferences, and thus be able to lead an active and healthy life" [26].

This concept has been growing in importance over the last decades, extending not only to food but also to all links in the food chain, from primary production through the processes of transformation, manufacturing, handling, and packaging to sale to consumers and the preparation of food by the final consumer.

In this context, a critical control point (CCP) "is a point in a step or procedure at which a control should be applied for the prevention or elimination of a hazard or reduction to an acceptable level" [24]. A critical control point hazard analysis (HACCP) makes it possible to identify, evaluate, and control significant CCPs throughout the food production process. Once these possible hazards have been identified, whether they constitute a critical control point (CCP) is assessed, and then the reference limits or critical limits are established by applying preventive measures that prevent non-conformities or deviations from these established limits [27–29].

Hazard Analysis Critical Control Point (HACCP) systems are defined as preventive programs focused on the production of safe food products [23]. The HACCP system emerged in 1959 when the Pillsbury company together with the United States Army and the National Aeronautics and Space Administration (NASA) developed a program to produce safe food. It was considered that the most important diseases that could affect astronauts were those related to the food they would consume [27]. The Pillsbury company introduced HACCP as the system that could offer the highest food safety because it controlled the entire production process from the beginning of the processing chain. The HACCP program had only three principles in its origins, while it currently has seven. The National Academy of Sciences (NAS) [30] and the National Advisory Committee on Microbiological Criteria for Foods (NACMF) is responsible for this expansion and its subsequent adoption by the Codex Alimentarius in 1993.

In 2003, a global consensus was reached for the use of HACCP in the global food supply. The Codex Alimentarius Food Hygiene Committee of the World Health Organization issued the Hazard Analysis and Critical Control Points guidelines for International Trade [31,32]. Soon after, the European Union, Canada, Australia, and Japan issued regulations requiring food businesses to develop and to implement food safety plans based on the NACMCF and the Codex Alimentarius frameworks [33].

Nowadays, the HACCP method is an internationally recognized systematic approach to food security that seeks to comply with the development and the realization of effective food safety practices [34]. It is based on seven principles that identify and control food safety hazards (Table 1) [34,35]. In addition, HACCP ensures that appropriate corrective actions are taken, where necessary, and that a registration system is available for documentation [36]. Under these principles, if any deviation occurs, it indicates that control has been lost. In that case, it is of paramount importance taking appropriate steps to restore control and to ensure that potentially dangerous products do not reach the consumer [37].

Table 1. Key principles of Critical Control Point Hazard Analysis (HACCP).

Number	Principle	Description
Principle 1	Perform a hazard analysis	Hazards should be identified and the associated risks that accompany them should be assessed at each stage of the production system and possible control measures should be described.
Principle 2	Determine Critical Control Points (CCPs)	Critical control points must be determined.
Principle 3	Set critical boundaries	A critical limit must be associated with each control measure to ensure that critical control points (CCPs) are under control.
Principle 4	Establish a surveillance system	A surveillance system should be implemented to ensure that CCPs are within critical limits and therefore under control
Principle 5	Establish corrective measures	Corrective measures to be taken when the surveillance system detects that a CCP is outside the control limits should be established
Principle 6	Establish verification procedures	Verification procedures should be established to confirm that the HACCP is functioning effectively and correctly.
Principle 7	Establish a system of registration and documentation	A system of record should be established on all procedures performed and the associated records.

An HACCP program is required to be built on a solid foundation of previous programs called prerequisite programs (PPRs) [38]. In accordance with what is described in the Codex Alimentarius [31,32], PPRs are based on the general principles of food hygiene [39]. Thus, PPRs provide basic environmental and operating conditions that are necessary to produce safe and healthy food. They address issues related to the cleaning and the disinfection of facilities and equipment, the supply and the use of supply water, pest prevention and control, staff handling practices and knowledge of food safety, and the identification and the location of food produced and marketed [29,40]; PPRs are built with different types of programs that develop each issue.

While the HACCP focuses on the dangers that depend solely on the production process of the wines, PPRs seek to eliminate all those dangers that depend on the work environment in the winery. The types of PPRs depend on the winery in which the HACCP is going to be implemented, and they have to be adapted in a specific way.

The application of HACCP has advantages, but it also has certain drawbacks. The main advantages from its application are guaranteeing food safety, allowing the control of each of the phases of the food chain that intervenes in the elaboration of a product, facilitating the supervision of the system by competent authorities, and its application to all food companies, regardless of their size or activity.

However, HACCP presents certain drawbacks, such as the need for: specific technical and material resources that are not always available to the industry; the training and the commitment of industry employees; methods for determining difficult critical control points [41]; and continuous evaluation and analysis of data [38].

Consequently, the aim of this study is to evaluate PPRs and HACCP implementation performance in wineries and the identification of the main barriers that hamper an optimal implementation.

2. Materials and Methods

2.1. Study Design

The performance of an HACCP program was assessed in a Protected Designation of Origin (PDO) "Vinos de Madrid" wineries sample. A survey was conducted in this sample in the last quarter of 2021. The collected data were analyzed with statistical methods using the SPSS for Windows software (IBM Corp. Released 2020. IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY, USA: IBM Corp.). Frequencies and central position values were calculated for all variables. A Spearman correlation coefficient (ρ) for nonparametric measure of rank correlation with a significance level of $p < 0.01$, Kruskal–Wallis non-parametric test and contingency table were carried out.

2.2. Sample Selection

Protected Designation of Origin "Vinos de Madrid" has a total population of 51 wineries. They produce 78% percent of the total wine production of the Madrid Region [42]. The sampling method was the non-probabilistic method. The sample selection was made using the researcher's previous information, instead of random selection [43].

The food-safety staff of wineries were asked about their Prerequisite and HACCP programs performance by a survey.

The survey was sent by email to every winery of the sample. The e-mailing was made on three occasions. In addition, an attempt at telephone contact was made by each of the wineries in the sample. A total of 21 wineries answered the survey.

The response rate (RT) was the percentage of the eligible sample from which information was obtained [43]. The RT was 21/50 representing 42% of the sample. The non-response rate (NRT) was the ratio between the number of rejections contacted and the number of all units selected [43]. The NRT was 29/50, representing 58% of the sample. The NRT reduced the sample size to 21 wineries up to a population of 51.

2.3. Survey Preparation

The survey design was carried out using a structured questionnaire. Each question had a limited alternative answer. These types of questionnaires are used for conclusive and descriptive research [43]. The survey had a total of 55 questions divided into 11 sections.

The first section consisted of seven questions related to annual red wine production and PPRs implementation. The first question identified the winery size according to its annual red wine production. We considered five groups when preparing the first question.

This group distribution covered all possible cases of responses according to the PDO "Vinos de Madrid" wineries annual red wine production [44]. The other six questions were focused on PPRs application. These questions asked about: how PPRs were drafted, communicated, and known by the winery staff; how PPRs application evidence and compliance were generated as updated records; and how PPRs are financed.

Sections two to ten were related to evaluating HACCP Principle 1 Perform a Hazard Analysis and HACCP Principle 2 Determine Critical Control Points (CCPs). These 9 sections contained a total of 37 items. These 37 items were prepared using the results obtained in several scientific and technical studies [23,45–48], and they provided qualitative information about the analysis and the control over the different hazards and critical control points (CCPs) in each stage of the red wine production process.

Each of the 37 items was assigned a qualitative scale "Never", "Hardly ever", "Usually", and "Always"; it was coded using a Likert scale [43]; and a quantitative variable was assigned to each item, respectively. Although the recommended Likert scale is five categories, we truncated the scale to four categories to eliminate the "neutral" option in a forced choice survey [49–51]. The numerical scale correspondence was "Never" with zero (0), "Hardly ever" with one (1), and "Usually" with two (2), and "Always" with three (3). A high variability in a quantitative variable was considered when its interquartile range value was equal or greater than two.

Section 11 contained 11 questions about the practical implementation of principles 3 to 7 on which the HACCP was based. The HACCP Guidelines were used for question preparation [29,52]. Eight items were dichotomous, and three items were multiple choice.

Principle 3 Setting Critical Limits was evaluated with a dichotomous question Yes/No. However, an affirmative option introduced the assessment of whether the winery only focused on the application of the legislation or if the winery also included the technical recommendations made by professional entities of viticulture.

Principle 4 Establishing a Surveillance System was evaluated with three questions. A dichotomous question about a surveillance system for CCPs establishment, a multiple-choice question about the CCPs implemented verification methods, and a dichotomous question about the implementation of a hazard monitoring actions program.

Principle 5 Establishing Corrective Measures was evaluated with one dichotomous question that asked about establishment of procedures for corrective measures.

Principle 6 Establish Verification Procedures was evaluated with four questions. A dichotomous question about the CCPs system establishment of verification procedures, a dichotomous question about the control frequency of each critical control point and the person responsible for carrying it out, a multiple-choice question about staff involved in verifying the effectiveness of the CCPS system, and a dichotomous question about conducting an annual HACCP internal audit that introduced the periodicity factor in the affirmative option.

Principle 7 Establish a System of Registration and Documentation was evaluated with two questions: a dichotomous question about HACCP registration and documentation implementation that introduced the factor of updating and the periodicity with which the documentary review was carried out; and a multiple-choice question about the type of documents included in the winery's HACCP.

The study tested three research hypotheses: Hypothesis 1 (H1) the effectiveness of the PPRs performance is different in each winery; Hypothesis 2 (H2) CCPs control performance is different for each of them; and Hypothesis 3 (H3) HACCP principles have different levels of implementation in wineries.

3. Results

The wineries were distributed according to their annual wine production. Four groups were considered instead of five, as we did not get any response for the group with an annual wine production greater than 500,000 L/year. Thus, annual wine production was recorded as follows: 47.6% of the wineries had an annual wine production between

25,001 and 100,000 L/year; 23.8% of the wineries had an annual wine production between 100,001 and 250,000 L/year; 23.8% of the wineries had an annual wine production of up to 25,000 L/year; and 4.8% of the wineries had an annual wine production between 250,001 and 500,000 L/year.

3.1. Prerequisites (PPRs) Implementation

In total, 91.5% of wineries had implemented a prerequisites program, regardless of their annual wine production; 9.5% of wineries had not implemented a prerequisites program.

The percentage of implementation of each type of program that made up a standard PPRs [29] in the wineries is showed in Figure 1.

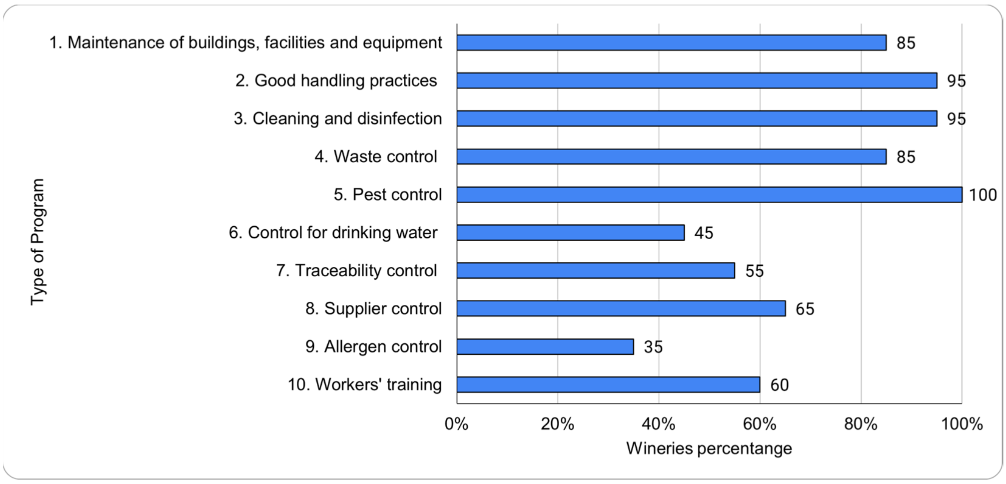

Figure 1. Percentage of wineries that have implemented each type of program included in a standard prerequisites program (PPRs).

A pest control program was implemented in all the wineries; 95% of wineries had implemented a cleaning and disinfection program and a good handling practices program; and 85% of wineries had a maintenance of buildings, facilities and equipment program and a waste control program. However, a traceability control program (55%), supplier control program (65%), workers' training program (60%), and control for drinking water program (45%) were implemented in nearly one out of two wineries. Finally, the allergen control program (35%) existed in only one out of three wineries.

Table 2 shows the results regarding the percentage of workers that have received training in good manufacturing practices in winemaking (GMP) and the percentage of workers with knowledge about the PPRs by type of winery, according to their annual wine production, and by the total of the wineries.

Table 2. GMP workers training and PPRs workers knowledge by type of winery, according to their annual wine production and by the total of the wineries.

Wine Annual Production	Percentage of Wineries Over Total	GMP Workers Training (%)			PPRs Workers Knowledge (%)		
		All	More than 50%	None	All	More than 50%	None
up to 25,000 L/year	23.8	50	0	50	40	20	20
between 25,001 and 100,000 L/year	47.6	36	55	9	50	50	0
between 100,001 and 250,000 L/year	23.8	60	40	0	80	20	0
between 250,001 and 500,000 L/year	4.8	100	0	0	100	0	0
Percentage of total wineries	100	48	38	14	62	33	5

A total of 81% of wineries had at least 50% of workers that had received training on good manufacturing practices in winemaking (GMP), the results obtained indicate that 81% of wineries had at least 50% of the staff trained in GMP.

Regarding their annual wine production, the wineries that exceed 100,000 L/year were those with the highest percentage of workers that had received GMP training.

In total, 95% of wineries indicated that more than 50% of workers had knowledge about their prerequisite program, while 62% of wineries had all their workers knowing their PPRs, and 38% of the wineries had more than 50% of their workers knowing their PPRs. In contrast, 20% of wineries with annual wine production up to 25,000 L/year hadn´t any workers with GMP training received.

The results obtained regarding the existence of an annual economic endowment through a detailed annual budget for the development of the prerequisite program are shown in Table 3.

Table 3. Annual budget of existing PPRs by type of winery, according to their annual wine production and by the total of the wineries.

Annual Wine Production	Percentage of Wineries Over Total	Annual Budget PPRs		
		Annual Specification (%)	No Detail (%)	None (%)
up to 25,000 L/year	23.8	20	20	60
between 25,001 and 100,000 L/year	47.6	0	82	18
between 100,001 and 250,000 L/year	23.8	40	60	0
between 250,001 and 500,000 L/year	4.8	100	0	0
Percentage of total wineries	100	24	62	14

A total of 62% of the wineries were making plans according to their needs without having a specific annual budget beforehand. This fact occurred in 82% of wineries between 25,001 and 100,000 L/year and in 60% of wineries between 100,001 and 250,000 L/year.

The existence of a specific annual budget occurred mainly in the largest wineries: 40% of the wineries between 100,001 and 250,000 L/year and in 100% of the wineries between 250,001 and 500,000 L/year, while 60% of wineries with up to 25,000 L/year did not have any annual budget.

3.2. Critical Control Point Hazard Analysis (HACCP) Implementation

A total of 76.2% of wineries had implemented a HACCP. One out four wineries had no HACCP. This occurred in 30% of wineries with an annual production between 25,001 and 100,000 L/year, in 20% of wineries with an annual production between 250,001 and 500,000 L/year, and 20% of wineries with production up to 25,000 L/year.

3.2.1. Performance in Principles One and Two: Critical Control Points

The results of CCPs control performance are shown in Table 4. This contingency table [43] is formed by the medians of each of the categorical variables associated to each CCP analyzed. Variables appear in rows and their median values appear in columns. In addition, the last right column shows which variables have a high variability.

Five groups were determined considering the median value of each variable and the existence of high variability measured by the interquartile range.

Group I is formed by variables with a median equal to zero, corresponding to the fact that the CCPs linked to "Never" were not controlled. Additionally, variables have a high variability. Thus, VAR2.3 and VAR4.1 belong to this group, and they are shown with a red cell and "Y" in Table 4.

Group II is formed by variables with a median equal to one, corresponding to the fact that the CCPs linked to "Hardly ever" were controlled. Additionally, variables have a high variability. Thus, VAR2.1, VAR8.1, and VAR9.3 belong to this group, and they are shown with an orange cell and "Y" in Table 4.

Table 4. Contingency table of the medians of each variable associated to each evaluated CCP.

	Frequencies					
Winemaking Steps	**Variable/Critical Control Point (CCP)**	**Always (3)**	**Usually (2)**	**Hardly Ever (1)**	**Never (0)**	**High Variability**
1. Harvest and grape transportation	VAR1.1 Grape inspection previous harvest in vineyards.	■				Y
	VAR1.2 Grape inspection during harvest in vineyards.	■				
	VAR1.3 Transportation time of harvest from vineyards to winery.	■				Y
2. Harvest reception in the winery	VAR2.1 Presence of fungicide residues and/or pesticides in grapes.			■		Y
	VAR2.2 Presence of mycotoxins from grape rot.	■				
	VAR2.3 Contamination by metals (Cadmium, Lead, Arsenic) in grapes.				■	Y
	VAR2.4 Contamination by plant residues, dust and/or metal elements.	■				
3. Pre-hatching treatments	VAR3.1 Vat cleaning to eliminate residues of microorganisms.	■				
	VAR3.2 No residues of cleaning and disinfection products in vats.	■				
4. Grapes crushing and must pumping	VAR4.1 Time that remains the must in the crusher after crushing.				■	Y
	VAR4.2 Cleaning of crushing equipment.	■				
	VAR4.3 No residues of cleaning and disinfection products in vats.	■				
5. Sulphited and vatted	VAR5.1 Safety and purity of the additives.		■			Y
	VAR5.2 No microorganisms in equipment and vats.	■				
6. Alcoholic fermentation, maceration, vat emptying, pressing, malolactic fermentation	VAR6.1 Concentration of ethylocarbamate in fermented must.		■			Y
	VAR6.2 Concentration of sulphur dioxide in fermented must.	■				
	VAR6.3 Purity and safety of yeasts.	■				Y
	VAR6.4 Temperature during fermentation.	■				
	VAR6.5 pH of red wine during malolactic fermentation.	■				
	VAR6.6 Hygiene during vat emptying/pressing operations.	■				
	VAR6.7 Cleaning of pressing equipment.	■				Y
7. Racking, clarification, and filtration	VAR7.1 Cleaning procedures for vats and racking equipment.	■				
	VAR7.2 Maintenance and cleaning of the facilities during racking.	■				
	VAR7.3 Purity and safety of agents used as clarifiers of the wine.	■				Y
	VAR7.4 No residues of clarifiers in the wine.		■			Y
	VAR7.5 No weird elements from filters in the wine.	■				
	VAR7.6 Hygiene during clarification and filtering operations.	■				
	VAR7.7 No residues of cleaning and disinfection products in vats.	■				
8. Cold stabilization	VAR8.1 Limit concentrations of metals (traces of As, Cu, Pb) in the wine.			■		Y
	VAR8.2 Additives accepted by current food legislation.	■				
9. Bottling and labelling	VAR9.1 Bottle cleaning procedures.		■			Y
	VAR9.2 Cleaning procedures of the bottling line.	■				
	VAR9.3 No microorganisms in the bottling line.			■		Y
	VAR9.4 No microorganisms in bottle cap.	■				Y
	VAR9.5 Correct coding of the label used on the bottles.	■				
	VAR9.6 Correct description of allergen information on bottle labels.	■				
	VAR9.7 Correct description of P.D.O. information on bottle labels.	■				

Group I and Group II represent the Critical Control Points (CCPs) that are worst controlled in wineries, and they therefore pose a high risk for the safety of the final product.

Figure 2 shows that absence of contamination control by metals (cadmium, lead, arsenic) in grapes at the harvest reception and time control that must be kept in the crusher are the critical points not controlled in 50% of wineries. Critical points that are poorly controlled in 50% of wineries include: control over fungicide residues and/or pesticides in grapes at the harvest reception in the winery, control of the concentration limits of metals (traces of As, Cu, Pb) in the wine during cold stabilization, and controlling the absence of microorganisms in the bottling line at the bottling and labelling stage. A strong positive correlation was found between the presence of fungicide residues and/or pesticides in grapes and contamination by metals (cadmium, lead, arsenic) in grapes (ρ = 0.850).

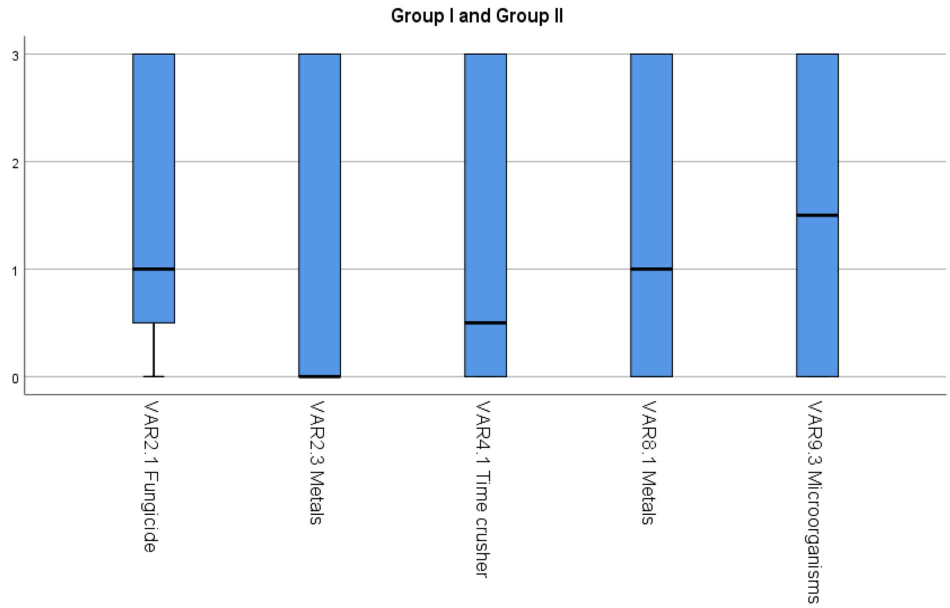

Figure 2. Median and range interquartile for variables included in Group I and Group II.

Group III is formed by variables with a median equal to two, corresponding to the fact that the CCPs linked to "Usually" were controlled. Additionally, variables have a high variability. Thus, VAR5.1, VAR6.1, VAR7.4, and VAR9.1 belong to this group, and they are shown with a light green cell and "Y" in Table 4.

Group IV is formed by variables with a median equal to three, corresponding to the fact that the CCPs linked to "Always" were controlled. Additionally, variables have a high variability. Thus, VAR1.1, VAR1.3, VAR6.9, VAR7.3 and VAR9.4 belong to this group, and they are shown with a dark green cell and "Y" on Table 4.

Group III and Group IV represent the Critical Control Points (CCPs) that are well controlled in at least 50% of the wineries, however, there is a high variability that shows a lack of control in the other 50%. Figure 3 shows these critical control points: grape inspection during the previous harvest in vineyards and the transportation time of the harvest from vineyards to wineries; the safety and the purity control of the additives used in the sulphited and the vatted stage; control of the concentration of ethylocarbamate in fermented must; the purity and the safety control of yeasts for fermentation; control of the cleaning of pressing equipment after pressing; the purity and the safety control of agents used as clarifiers; control of residue from wine clarifiers, control of bottle cleaning procedures, and control of microorganisms in bottle caps.

A strong positive correlation was found between the safety and the purity control of additives and the safety control of agents used as clarifiers (ρ = 0.929), the safety and the purity control of additives and the control of residue from wine clarifiers (ρ = 0.916), the purity and the safety of yeasts and the concentration of ethylocarbamate in fermented must (ρ = 0.831), the safety control of agents used as clarifiers (ρ = 0.929), and the control of residue from wine clarifiers (ρ = 0.916).

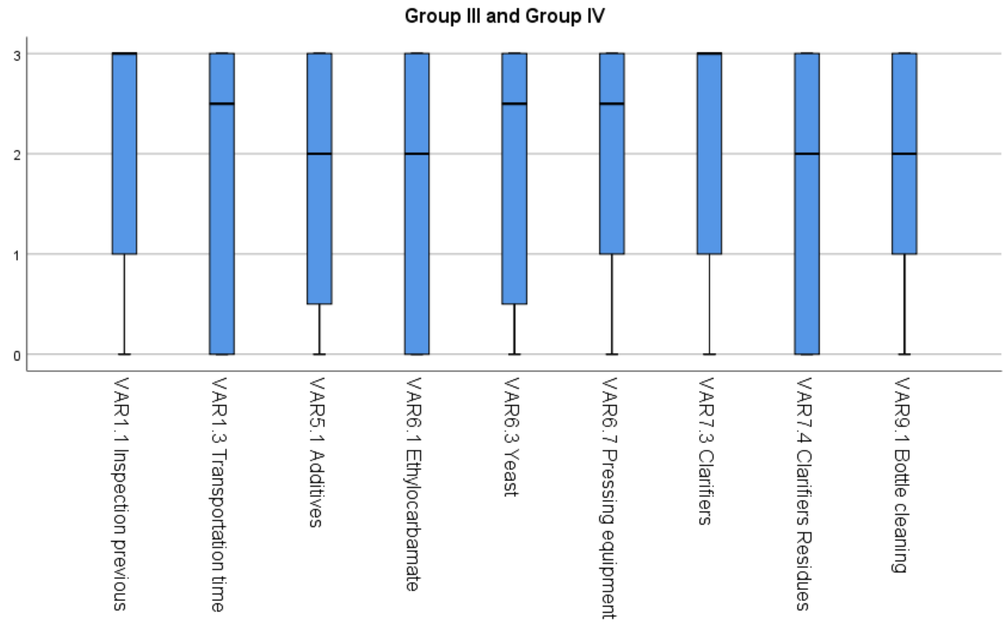

Figure 3. Median and range interquartile for variables included in Group III and Group IV.

Group V is formed by variables with a median equal to three, corresponding to the fact that the CCPs linked to "Always" were controlled. These variables represent all Critical Control Points that are well controlled, and they are shown with a dark green cell in Table 4.

A Kruskal–Wallis test for independent samples in all groups defined on the null hypothesis that the distribution of the qualitative variable is the same between the different categories of annual wine production allowed for the consideration that the median and its variability is the same regardless of the annual wine production of the wineries. The result of this test accepted the null hypothesis for all the variables studied, except for VAR6.1

3.2.2. Performance in Principles Three to Seven

The results of the practical implementation of HACCP Principles three to seven are reflected in Table 5, considering annual wine production of wineries. No data was received for wineries over 250,001 L/year.

Table 5. Practical implementation of principles by type of winery, according to their annual wine production and by the total of the wineries.

Annual Wine Production	% Over Total Wineries	Principle 3			Principle 4		Principle 5		Principle 6		Principle 7		
		Critical Limits (%)			Surveillance System (%)		Corrective Measures (%)		Verification Procedure (%)		Registration and Documentation System (%)		
		No	Yes (a)	Yes (b)	No	Yes	No	Yes	No	YES	No	Yes (c)	Yes (d)
up to 25,000 L/year	25	0	25	75	0	100	25	75	25	75	0	25	75
between 25,001 and 100,000 L/year	50	12.5	37.5	50	12.5	87.5	50	50	50	50	12.5	50	37.5
between 100,001 and 250,000 L/year	25	0	50	50	0	100	0	100	0	100	0	50	50
Percentage of total wineries	**100**	**6.2**	**37.5**	**56.3**	**6.2**	**93.8**	**31.3**	**68.7**	**31.3**	**68.7**	**6.2**	**43.8**	**50**

Regarding Principle 3, Table 5 shows that 56.3% of wineries established the target levels and critical limits for each of the CCPs identified, following the mandatory regulations and/or professional technical recommendations. A total of 37.5% of wineries established target level and critical limits, but only for those in which there are applicable mandatory regulations. Only 6.2% of wineries did not set any target or limit for CCPs. The smallest wineries, producing up to 25,000 L/year, showed the best performance for this principle.

In total, 93.8% of wineries implemented a surveillance system of critical control points in accordance with Principle 4.

The sum of 68.7% of wineries had a written procedure for the establishment of the corrective measures to be applied in case of identifying deviations in each of the CCPs following Principle 5.

To verify the effectiveness of the HACCP system in compliance with Principle 6, 68.7% of wineries had a procedure.

The worst performance for Principles 5 and 6 was shown in wineries between 25,001 and 100,000 L/year. One out of two did not implement a procedure of corrective measures or a verification procedure.

With respect to Principle 7, 50% of wineries had a complete and periodically updated registration and documentation system; 43.8% of the wineries had written records and documents, but they were incomplete or not updated periodically.

The type of verification methods used by the wineries for the surveillance of CCPs were evaluated according to Principle 4: 93.8% of the wineries performed visual observation, 87.5% performed physical determinations (temperature, relative humidity, pH), 81.3% performed sensory assessment (smell, taste, aroma, texture), 81.3% performed chemical analyses, and 43.7% performed microbiological analyses. In addition, 81.3% of wineries had a written surveillance program that detailed the actions for hazards and their CCPs monitoring at each wine production stage.

Regarding the implementation of Principle 6, the profiles of professionals that were involved in the verification of the HACCP system were as follows: 100% oenologists, 53.8% managers, 46.2% of winery owners, 15.4% quality managers or similar, and 15.4% winery operators.

Table 6 shows the control frequency and the audit achievements in the wineries. These two elements serve to verify the practical implementation of Principle 6.

Table 6. Control frequency and audit achievements by type of winery, according to their annual wine production and by the total of the wineries.

Annual Wine Production	**% Over Total Wineries**	**Principle 6**				
		Frequency (%)		**Audits (%)**		
		No	**Yes**	**No**	**Yes (e)**	**Yes (f)**
up to 25,000 L/year	28.6	25	75	25	25	50
between 25,001 and 100,000 L/year	42.8	33.3	66.7	50	33.3	16.7
between 100,001 y 250,000 L/year	28.6	25	75	25	25	50
Percentage of total wineries	**100**	**28.6**	**71.4**	**35.7**	**28.6**	**35.7**

In total, 71.4% of the wineries detailed the control frequency of each CCP and the person(s) responsible for carrying it out.

A total of 35.7% of wineries did not carry out audits, 35.7% of wineries carried out annual audits, and 28.7% of wineries did audits but with a periodicity greater than a year.

Principle 7 is developed by 9 types of documents. The percentage of total wineries that have included each type of document in their HACCP system is shown in Figure 4. All wineries had a description of wine production process stages guide, 100% of wineries had a Critical Control Points (CCPs) identification document, 93.8% had a hazard analysis and preventive measures identification document, 81.3% had an HACCP on-going records, 88.8% had an HACCP team members list, 88.8% had a surveillance program with monitoring activities, 56.3% had a corrective measures procedure, 55% had a documents management system and a registration procedure, and 43.8% had results of verifications and internal audit documents.

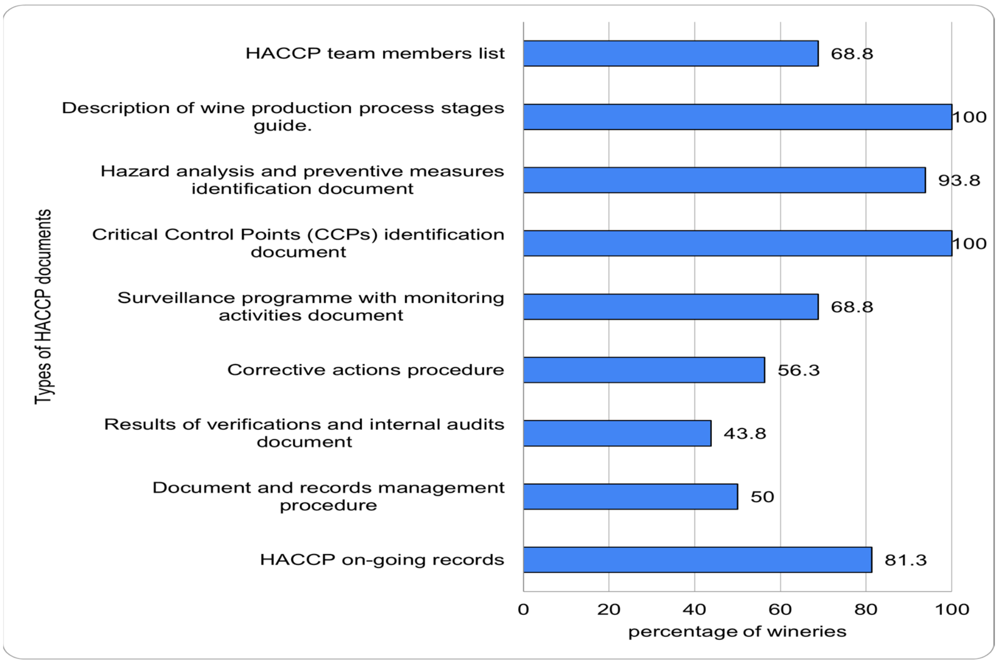

Figure 4. The percentage of total wineries that have included each type of document in their HACCP system.

4. Discussion

The correct implementation of prerequisites programs and a Hazard Analysis Critical Control Point (HACCP) system are essential to prevent illnesses and to ensure food safety for people. Although, the methodologies of practical development of both instruments for food and hygiene safety is widely spread and studied worldwide, it has been proven that there are companies that still do not manage to obtain the maximum effectiveness in food safety [53–55]. This study provides an overview of performance in the implementation of prerequisite programs and the HACCP in wineries in the Madrid Region

The study results prove Hypothesis 1. They show that the effectiveness of the PRRs performance is different in each winery. Although PPRs implementation is widespread in DPO "Vinos de Madrid "wineries, their practical deployment level through compliance with prerequisite plans (PPR) is different. A total of 95% of wineries have a PPR in place, regardless of their annual wine production level; although, their PPRs practical implementation are different in terms of the types of plans implemented, the operators' levels of training and knowledge about them, and the annual budget allocated for PPRs execution.

Thus, one hundred percent of the wineries have a pest control plan, while only 35% carry out an allergen control plan. Most of the wineries have operators trained in good winemaking practices and prerequisites, but only one out of four have established annual PPRs budgets. Both factors, workers' training levels and economic allocation appear as causes of the diversity in the level of deployment of PPRs.

It is recognized that without a good implementation of PPRs, it is difficult to correctly develop a HACCP.

The study reveals that Hypotheses 2 is true. The CCPs performance control is different for each of the 37 evaluated CCPs (see Table 4). A total of 22 CCPs are well-evaluated by the wineries. However, there are significant differences among another 15 CCPs depending on each winery. The worst control performance among wineries for CCPs appears related to chemical controls of metals traces, fungicides and pesticides in grapes or wine, biological controls of microorganisms in equipment, and operations stage controls as the remaining time of the must in crushers. Deficiently controlled CCPs assume that hazards such as the appearance of microorganisms, trace metals, fungicides, pesticides or other dangerous products in grapes or wine may occur [23,46,56].

Hypotheses 3 is proven. The results show HACCP principles have different implementation levels in wineries. The worst implemented HACCP principles are Principle 5 and Principle 6. Only 78.7% of the wineries had established a corrective measures procedure and a verification procedure.

Additionally, documentary and registration systems present great variability in their practical implementation in wineries. Thus, most have identification documents of critical control points and hazard analysis and determination of preventive measures, while less than half do not have the results of verifications and internal audits.

In total, 93.8% of wineries had established a CCP monitoring system, but microbiological testing methods were used by less than 50% of wineries. In addition, in almost half of the wineries this surveillance falls solely on the oenologist, without involving the rest of their workers.

5. Conclusions

This work demonstrates the need to continue improving in the technical implementation of the HACCP methodology and in training workers about food safety in wineries.

According to the barriers identified for the development and the implementation of HACCP by Vela & Fernández [38], the establishment of new CCPs surveillance formats involving the different professionals working in the wineries (enologist, manager, winery operators, quality managers) will improve performance in the CCPs surveillance, and by extension, the deployment level of the entire HACCP. Mojca Jevsnik stressed the importance of a motivated, satisfied, and qualified personnel to assure an efficient HACCP [57].

A good implementation of PPR and HACCP contributes to eliminating food safety risks that compromise people's health. The first step forces the winery industry to improve the identification, analysis, and evaluation of hazards and CCPs. To do this, wineries must make improvements in their chemical and microbiological analysis laboratories. At the same time, they must invest in training and sensitization of all staff in matters aimed at methodological knowledge and a good development of PPRs and HACCP.

Leadership is essential to a good culture of safety [58]. Winery owners and managers must demonstrate a full commitment to the good functioning of food safety systems. This makes it easier for all workers to align with senior management to achieve the effectiveness of food safety systems.

Research on the analysis of training levels in food safety for each of the professionals' profiles working in the wineries is convenient, likewise research that relates the level of commitment of workers classes according to the level of training acquired on PPRs and HACCP.

Following these steps will help not only the wine industry but also the health of customers.

Author Contributions: Conceptualization, methodology, and formal analysis, J.L.-S.; conceptualization and supervision, M.T.G.-V.; supervision, A.I.G.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data used in this study are available on fair request to the corresponding authors.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Robertson, G.L. *Chapter In Food Packaging: Principles and Practice*; CRC press: Boca Raton, FL, USA, 2005.
2. European Commission. Commission Regulation (EC) No 606/2009 of 10 July 2009 laying down certain detailed rules for implementing Council Regulation (EC) No 479/2008 as regards the categories of grapevine products, oenological practices and the applicable restrictions. *Off. J. Eur. Union L* **2009**, *193*, 1–59.

3. European Commission. Commission Regulation (EC) No 423/2008 of 8 May 2008 on laying down certain detailed rules for implementing Council Regulation (EC) No 1493/1999 and establishing a community code of oenological practices and processes (Codified version). *Off. J. Eur. Union L* **2008**, *127*, 1–45.
4. European Council. Council Regulation (EC) No 479/2008 of 29 April 2008 on the common organization of the market in wine, amending Regulations (EC) No 1493/1999, (EC) No 1782/2003, (EC) No 1290/2005, (EC) No 3/2008 and repealing Regulations (EEC) No 2392/86 and (EC) No 1493/1999. *Off. J. Eur. Union L* **2008**, *148*, 1–61.
5. European Parliament & European Council. Regulation (EC) No 1333/2008 of the European Parliament and of the Council of 16 December 2008 on food additives (Text with EEA relevance). *Off. J. Eur. Union L* **2008**, *354*, 16–33.
6. European Commission. Commission Regulation (EU) No 1129/2011 of 11 November 2011 amending Annex II to Regulation (EC) No 1333/2008 of the European Parliament and of the Council by establishing a Union list of food additives. *Off. J. Eur. Union L* **2011**, *295*, 1–177.
7. European Commission. Amending Annex III to Regulation (EC) No 1333/2008 of the European Parliament and of the Council on food additives by establishing a Union list of food additives approved for use in food additives, food enzymes, food flavourings and nutrients (Text with EEA relevance). *Off. J. Eur. Union L* **2011**, *295*, 1–27.
8. Miller, K.V.; Block, D.E. A review of wine fermentation process modeling. *J. Food Eng.* **2020**, *273*, 109783. [CrossRef]
9. Casassa, L.F.; Harbertson, J.F. Extraction, evolution, and sensory impact of phenolic compounds during red wine maceration. *Annu. Rev. Food Sci. Technol.* **2014**, *5*, 83–109. [CrossRef]
10. Setford, P.C.; Jeffery, D.W.; Grbin, P.R.; Muhlack, R.A. Factors affecting extraction and evolution of phenolic compounds during red wine maceration and the role of process modelling. *Trends Food Sci. Technol.* **2017**, *69*, 106–117. [CrossRef]
11. Metivier, R.P.; Francis, F.J.; Clydesdale, F.M. Solvent extraction of anthocyanins from wine pomace. *J. Food Sci.* **1980**, *45*, 1099–1100. [CrossRef]
12. He, F.; Liang, N.; Mu, L.; Pan, Q.; Wang, J.; Reeves, M.J.; Duan, C. Anthocyanins and their variation in red wines I. Monomeric anthocyanins and their color expression. *Molecules* **2012**, *17*, 1571–1601.
13. Romero-Cascales, I.; Fernández-Fernández, J.I.; López-Roca, J.M.; Gómez-Plaza, E. The maceration process during winemaking extraction of anthocyanins from grape skins into wine. *Eur. Food Res. Technol.* **2005**, *221*, 163–167. [CrossRef]
14. Sablayrolles, J.M. Control of alcoholic fermentation in winemaking: Current situation and prospect. *Food Res. Int.* **2009**, *42*, 418–424. [CrossRef]
15. Davis, C.R.; Wibowo, D.; Eschenbruch, R.; Lee, T.H.; Fleet, G.H. Practical implications of malolactic fermentation: A review. *Am. J. Enol. Vitic.* **1985**, *36*, 290–301.
16. Lonvaud-Funel, A. *Lactic acid bacteria in the quality improvement and depreciation of wine. Lactic Acid Bacteria: Genetics, Metabolism and Applications*; Springer: Dordrecht, The Netherlands, 1999; pp. 317–331.
17. Vernhet, A. Red wine clarification and stabilization. In *Red Wine Technology*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 237–251.
18. Mierczynska-Vasilev, A.; Smith, P.A. Current state of knowledge and challenges in wine clarification. *Aust. J. Grape Wine Res.* **2015**, *21*, 615–626. [CrossRef]
19. Oliva, J.; Payá, P.; Cámara, M.Á.; Barba, A. Removal of famoxadone, fluquinconazole and trifloxystrobin residues in red wines: Effects of clarification and filtration processes. *J. Environ. Sci. Health Part B* **2007**, *42*, 775–781. [CrossRef]
20. McRae, J.M.; Mierczynska-Vasilev, A.; Soden, A.; Barker, A.M.; Day, M.P.; Smith, P.A. Effect of commercial-scale filtration on sensory and colloidal properties of red wines over 18 months bottle aging. *Am. J. Enol. Vitic.* **2017**, *68*, 263–274. [CrossRef]
21. Petronilho, S.; Rudnitskaya, A.; Coimbra, M.A.; Rocha, S.M. Comprehensive study of variety oenological potential using statistic tools for the efficient use of non-renewable resources. *Appl. Sci.* **2021**, *11*, 4003. [CrossRef]
22. Petronilho, S.; Lopez, R.; Ferreira, V.; Coimbra, M.A.; Rocha, S.M. Revealing the usefulness of aroma networks to explain wine aroma properties: A case study of Portuguese wines. *Molecules* **2020**, *25*, 272. [CrossRef]
23. Christaki, T.; Tzia, C. Quality and safety assurance in winemaking. *Food Control* **2002**, *13*, 503–517. [CrossRef]
24. Lee, J.C.; Daraba, A.; Voidarou, C.; Rozos, G.; El Enshasy, H.A.; Varzakas, T. Implementation of Food Safety Management Systems along with Other Management Tools (HAZOP, FMEA, Ishikawa, Pareto). The Case Study of Listeria monocytogenes and Correlation with Microbiological Criteria. *Foods* **2021**, *10*, 2169.
25. European Parliament & European Council (2002) Regulation (EC) No 178/2002 of the European Parliament and of The Council of 28 January2002 laying down the general principles and requirements of food law, establishing the European Food SafetyAuthorityand laying down procedures in matters of food safety. *Off. J. Eur. Union L* **2002**, *31*, 1–24.
26. Food and Agriculture Organization. *La Seguridad Alimentaria: Información Para La Toma De Decisiones*; FAO: Roma, Italy, 2011.
27. Bauman, H.E. The origin and concept of HACCP. In *HACCP in Meat, Poultry, and Fish Processing*; Springer: Berlin/Heidelberg, Germany, 1995; pp. 1–7.
28. Sperber, W.H. *Determining Critical Control Points*; Pierson, M.D., Corlett, D.A., Eds.; HACCP: Principles and Applications; Springer: Boston, MA, USA, 1992; pp. 39–49.
29. European Commission. Commission Notice on the implementation of food safety management systems covering prerequisite programs (PRPs) and procedures based on the HACCP principles, including the facilitation/flexibility of the implementation in certain food businesses. *Off. J. Eur. Union L* **2016**, *278*, 1–32.

30. National Research Council. *An Evaluation of the Role of Microbiological Criteria for Foods and Food Ingredients*; National Academic Press: Washington, DC, USA, 1985.
31. Codex Alimentarius. General Principles of Food Hygiene, Update. Available online: https://www.fao.org/fao-whocodexalimentarius/shproxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXC%2B1-1969%252FCXC_001e.pdf (accessed on 17 October 2021).
32. Codex Alimentarius Commission Recommended International Code of Practice General Principles of Food Hygiene. CAC/RCP Rev. 2003. CXC 1-1969. Available online: https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXC%2B1-1969%252FCXC_001e.pdf (accessed on 18 October 2021).
33. Bernard, D.; Scott, V.N. Hazard Analysis and Critical Control. Point System: Use in Controlling Microbiological Hazards. In *Food Microbiology: Fundamentals and Frontiers*, 3rd ed.; American Society of Microbiology: Washington, DC, USA, 2007; pp. 971–985.
34. Mortimore, S.; Wallace, C. *HACCP: A Practical Approach*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2013.
35. Dominguez, R.A.; Espinosa, M.d.M.; Dominguez, M.; Romero, L. Lean 6S in Food Production: HACCP as a Benchmark for the Sixth S "Safety". *Sustainability* **2021**, *13*, 12577. [CrossRef]
36. Gehring, K.B.; Kirkpatrick, R. Hazard Analysis and Critical Control Points (HACCP). In *Food Safety Engineering*; Springer: Cham, Switzerland, 2020; pp. 191–204.
37. Hulebak, K.L.; Schlosser, W. Hazard analysis and critical control point (HACCP) history and conceptual overview. *Risk Anal.* **2002**, *22*, 547–552. [CrossRef] [PubMed]
38. Vela, A.R.; Fernández, J.M. Barriers for the developing and implementation of HACCP plans: Results from a Spanish regional survey. *Food Control* **2003**, *14*, 333–337. [CrossRef]
39. European Parliament. Regulation (EC) No 852/2004 of the European Parliament and of The Council of 29 April 2004 on the hygiene of foodstuffs. *Off. J. Eur. Union L* **2004**, *139*, 1–54.
40. Panghal, A.; Chhikara, N.; Sindhu, N.; Jaglan, S. Role of Food Safety Management Systems in safe food production: A review. *J. Food Saf.* **2018**, *38*, e12464. [CrossRef]
41. Panisello, P.J.; Quantick, P.C. Technical barriers to hazard analysis critical control point (HACCP). *Food Control* **2001**, *12*, 165–173. [CrossRef]
42. Consejo Regulador de Vinos de Madrid Denominación de Origen Protegida. Available online: https://www.comunidad.madrid/transparencia/unidad-organizativa-responsable/consejo-regulador-denominacion-origen-vinos-madrid (accessed on 18 October 2021).
43. Abascal, E.; Grande, I. *Análisis De Encuestas*; ESIC Editorial: Madrid, Spain, 2005; pp. 26–29.
44. Arribas Fernández, E. Memoria. Available online: https://vinosdemadrid.es/ (accessed on 18 October 2021).
45. Benito, S. The Management of Compounds that Influence Human Health in Modern Winemaking from an HACCP Point of View. *Fermentation* **2019**, *5*, 33. [CrossRef]
46. Magan, N. Mycotoxin contamination of food in Europe: Early detection and prevention strategies. *Mycopathologia* **2006**, *162*, 245–253. [CrossRef] [PubMed]
47. Chen, H.; Chen, Y.; Liu, S.; Yang, H.; Chen, C.; Chen, Y. Establishment the critical control point methodologies of seven major food processes in the catering industry to meet the core concepts of ISO 22000:2018 based on the Taiwanese experience. *J. Food Saf.* **2019**, *39*, e12691. [CrossRef]
48. Organisation Internationale de la Vigne et du Vin. *International Enological Codex*; Organisation Internationale de la Vigne et du Vin.: Paris, France, 2022.
49. Allen, I.E.; Seaman, C.A. Likert scales and data analyses. *Qual. Prog.* **2007**, *40*, 64–65.
50. Wakita, T.; Ueshima, N.; Noguchi, H. Psychological distance between categories in the Likert scale: Comparing different numbers of options. *Educ. Psychol. Meas.* **2012**, *72*, 533–546. [CrossRef]
51. Bendig, A.W. The reliability of self-ratings as a function of the amount of verbal anchoring and of the number of categories on the scale. *J. Appl. Psychol.* **1953**, *37*, 38. [CrossRef]
52. Baş, M.; Yüksel, M.; Çavuşoğlu, T. Difficulties and barriers for the implementing of HACCP and food safety systems in food businesses in Turkey. *Food Control* **2007**, *18*, 124–130. [CrossRef]
53. Walker, E.; Pritchard, C.; Forsythe, S. Hazard analysis critical control point and prerequisite programme implementation in small and medium size food businesses. *Food Control* **2003**, *14*, 169–174. [CrossRef]
54. Ramalho, V.; de Moura, A.P.; Cunha, L.M. Why do small business butcher shops fail to fully implement HACCP? *Food Control* **2015**, *49*, 85–91. [CrossRef]
55. Woh, P.Y.; Thong, K.L.; Behnke, J.M.; Lewis, J.W.; Mohd Zain, S.N. Evaluation of basic knowledge on food safety and food handling practices amongst migrant food handlers in Peninsular Malaysia. *Food Control* **2016**, *70*, 64–73. [CrossRef]
56. Martinez-Rodriguez, A.J.; Carrascosa, A.V. HACCP to control microbial safety hazards during winemaking: Ochratoxin A. *Food Control* **2009**, *20*, 469–475. [CrossRef]
57. Jevšnik, M.; Hlebec, V.; Raspor, P. Food safety knowledge and practices among food handlers in Slovenia. *Food Control* **2008**, *19*, 1107–1118. [CrossRef]
58. Chen, H.; Liou, B.; Hsu, K.; Chen, C.; Chuang, P. Implementation of food safety management systems that meets ISO 22000:2018 and HACCP: A case study of capsule biotechnology products of chaga mushroom. *J. Food Sci.* **2021**, *86*, 40–54. [CrossRef] [PubMed]

4.2 Article two

López-Santiago, J., García, A. I. G., Villarino, A. G., Som, A. M., & Gómez-Villarino, M. T. (2024). **Assessing wineries' performance in managing critical control points for arsenic, lead, and cadmium contamination risk in the wine-making industry: A survey-based analysis utilizing performance indicators as a results tool.** Heliyon, 10(1).

The research addresses the **specific objective 3 (SO-3)**, focusing on the control of CCPs as an instrument to evaluate sustainability in wine production. The study explores how wineries manage worker training, follow legal regulations, and check for harmful substances like arsenic, cadmium, and lead in grapes and wines. It elaborates three FSMS performance indicators—FS Worker Training (FSWT), Legislation Identification and Updating (LIU), and Critical Control Point Chemical Analysis Performance (CCP-MCHEM)—to understand winemaking practices.

A key finding is that most surveyed wineries take FS seriously, with 96.9% following regulations and 93.8% adhering to standards. Larger wineries have more workers trained in both GMP and CCPs, aligning with industry expectations due to their resources. Notably, there is a positive connection between GMP and CCPs training, showing a systematic approach to ensuring FS. Smaller wineries also have a high percentage of trained workers, but their absolute numbers may be limited by their workforce size.

Examining legislative compliance and Heavy Metal Food Contamination Risk (HMFCR) laws, smaller wineries show suboptimal awareness of critical regulations. The use of information from the National Agency (AESAN) is low overall, indicating a widespread industry gap in using available resources for regulatory compliance. A positive correlation between workers' CCPs training and identifying HMFCR legislation adds complexity, highlighting the relationship between employee training and regulatory compliance.

Analysing vineyard chemical analysis, a positive connection exists between soil analysis and fertilizer information. However, there is a notable lack of information on harmful substances like arsenic, cadmium, and lead, especially in smaller wineries. This gap poses a challenge in assessing and mitigating contamination risks during winemaking, potentially affecting the final product's quality and safety.

Introducing the CCP-MCHEM indicator, the research evaluates wineries' progress in chemical analysis for harmful substances. Larger wineries perform better, but differences persist across winery sizes, emphasizing the need for targeted interventions recognizing the unique challenges faced by wineries of varying scales.

The findings provide insights into the research questions regarding the application of CCP control, as a foundation of HACCP, for evaluating winery performance in terms of sustainability. Specifically, they address the poorly controlled CCPs identified as posing serious health risks. Furthermore, the results clarify a method for obtaining a quantitative measure of sustainability within the wine industry using three qualitative performance indicators.

Heliyon 10 (2024) e22962

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Assessing wineries' performance in managing critical control points for arsenic, lead, and cadmium contamination risk in the wine-making industry: A survey-based analysis utilizing performance indicators as a results tool

Jesús López-Santiago [a,*], Ana Isabel García García [a], Alejandro Gómez Villarino [b], Amelia Md Som [c], María Teresa Gómez-Villarino [a]

[a] Agroforestry Engineering Department, School of Agricultural, Food and Biosystems Engineering, Universidad Politécnica de Madrid, Spain
[b] Independent Consultant, Spain
[c] Malaysian Institute of Chemical & Bioengineering Technology (UniKL MICET), Universiti Kuala Lumpur, Malaysia

A R T I C L E I N F O

Keywords:
Food safety
Food hazards
HACCP
Critical control points
Beverages

A B S T R A C T

Human health hazards appear in wine production. Wineries have implemented food safety management systems to control food hazards through Hazard Analysis Critical Control Point (HACCP). Wine-making industry applies HACCP by evaluating Critical Control Points (CCPs). One of the CCPs that exhibits inadequate control is the potential contamination risk of arsenic, cadmium, and lead throughout the winemaking procedure. Wineries performance level about controlling CCPs related to contamination risk by arsenic, cadmium and lead in the winemaking were analyzed. A sixteen-question questionnaire was made to achieve this research. Three indicators were calculated for training, legislation, and analysis performance components in CCPs control. Results revealed that wineries fault in analysis and legislation components. Identification and updating of legislation about As, Cd and Pb contamination risk is in starting performance level for wineries that produce less than 250,000 L/year wineries. Analysis performance level is even lower than legislation. Only one out of every three wineries possess information regarding the concentrations of arsenic, cadmium, and lead in the soils of vineyards where grapes are cultivated. Furthermore, the availability of data on their available concentrations in the soil solution is even more limited. Those wineries that controlled As, Cd and Pb concentrations make it according to official recommendations using techniques based on atomic absorption spectrometry. However, there is a lack of this spectrometry equipment in the wineries own laboratories.

1. Introduction

Food hazards in winemaking arise from various sources, including improper practices by winery staff, equipment and infrastructure used in winemaking, and environmental factors. Cross-contamination and allergens have been identified as the primary causes of food safety incident [1]. The accumulation of residues, which can have physical, chemical, or microbiological origins, is a major concern in

* Corresponding author.
E-mail addresses: jesus.lopez.santiago@upm.es (J. López-Santiago), ai.garcia@upm.es (A.I. García García), agv@ecoworking.es (A.G. Villarino), ameliamds@unikl.edu.my (A.M. Som), teresa.gomez.villarino@upm.es (M.T. Gómez-Villarino).

https://doi.org/10.1016/j.heliyon.2023.e22962
Received 23 February 2023; Received in revised form 22 November 2023; Accepted 22 November 2023
Available online 5 December 2023

wine production. In this context, studies have shown that excessive intake of ions such as arsenic, lead and cadmium can be toxics for human health [2,3].

Metals and metalloids present in grapes primarily come from the soil and the application of fertilizers, pesticides, and fungicides containing substances like cadmium, copper, manganese, lead, or zinc [4]. Spanish soils naturally have elevated concentrations of these elements, particularly arsenic [5–7]. High arsenic concentrations in vineyard soils in central Spain have been reported by Jimenez-Ballesta (2023) [8]. Andersson and Nilsson found that chemical elements like cadmium, lead and arsenic from sewage sludge fertilization (84 t/ha) remained in the top 20 cm of the soil for twelve years [9]. However, vines and grapes are not hyperaccumulators of potentially toxic soil elements (PTEs), with higher concentrations of PTEs found on the outer parts (leaf and petiole) compared to the inner parts of the grape (skin, pulp, and seed) [10].

Controlling metals and metalloids food hazards is achieved by addressing associated food risks. Wineries utilize Food Safety Management Systems (FSMS) as to manage these risks. Good manufacturing practices (GMP) in winery operations establish hygienic conditions aimed at preventing the presence of hazardous agents [11].

FSMS typically include Prerequisites Programmes (PRPs) [12] and a Hazard Analysis Critical Control Point (HACCP) [13,14] in accordance with the reference regulatory framework in the European Union [15]. PRPs ensure appropriated environmental and operational conditions necessary for producing safe and healthy food. PRPs address issues to the supply and use of sanitary water, equipment and facility cleaning and disinfection, pest control and prevention, good manufacturing practices or staff knowledge of food safety, allergens and food traceability [16].

HACCP is a globally recognized and standardized methodology for ensuring food safety. It is based on seven principles that focus on identifying and controlling food safety hazards. The first three principles involve hazard identification, determining CCPs and establishing of critical limits of these CCPs to ensure food safety [17,18]. Also, a HACCP plan encompasses control measures that can be employed to proactively prevent, mitigate, or eliminate potential hazards. Regular monitoring and verification procedures, including

Table 1
Main CCPs and oPRPs in the production of young wine.

Wine-making process steps	Critical Control Point vs Operational Prerequisite Programme
Harvest and grape transportation	oPRP 2.1 Vineyards inspection prior to the harvest to know the general condition of the grapes. oPRP 2.2 Vineyards inspection during the harvest to know the state of grapes. oPRP 2.3 Time control that takes to transport the harvest to the winery.
Harvest reception in winery	oPRP 3.1 Control of residues of fungicides and/or pesticides existing in grapes intended for winemaking. oPRP 3.2 Mycotoxins control from grape rot. oPRP 3.3 Control of the presence of contamination by plant debris, dust and/or metallic elements. CCP 3.1 Control of the presence of contamination by metals (Cd, Pb, As) in the grapes.
Pre-hatching treatments	oPRP 4.1 Control of the cleanliness of the tanks to eliminate residues of microorganisms. oPRP 4.2 Control of the absence of cleaning and disinfection products in the tanks.
Grape crushing and must pumping	oPRP 5.1 Control of the cleanliness of crushing equipment. oPRP 5.2 Control of the absence of cleaning and disinfection products in tanks, press and pumping equipment. CCP 5.1 Control of the wort maintenance time in the crusher.
Sulphited and vatted	oPRP 6.2 Control of the absence of microorganisms in equipment and tanks. CCP 6.1 Control of the safety and purity of additives
Alcoholic fermentation, maceration, vat emptying, pressing and malolactic fermentation	oPRP 7.1 Control of the concentration of ethylocarbamate in fermented must. oPRP 7.2 Control of hygiene during racking and pressing operations. oPRP 7.3 Control of the cleanliness of pressing equipment. CCP 7.1 Control of sulfur dioxide in fermented must. CCP 7.2 Control of the purity and safety of yeasts. CCP 7.3 Temperature control during fermentation. CCP 7.4 Control of the pH of red wine during malolactic fermentation.
Racking, clarification, and filtration	oPRP 8.1 Control of the cleaning procedures of tanks and transfer equipment. oPRP 8.2 Control of maintenance and cleaning procedures of the facilities. oPRP 8.3 Control of hygiene operations during clarification and filtering operations. oPRP 8.4 Control of the absence of cleaning and disinfection products in tanks and equipment. oPRP 8.5 Control of the absence of foreign elements from the filters in red wine. CCP 8.1 Control of the purity and safety of agents used as clarifiers in red wine. CCP 8.2 Control of the absence of residues of agents used as clarifiers in red wine.
Cold stabilization	CCP 9.1 Control of limit concentrations of metals (traces of As, Cu, Pb) in red wine. CCP 9.2 Control of the additives used are those allowed by current food legislation.
Bottling and labelling	oPRP 10.1 Control of bottle cleaning procedures. oPRP 10.2 Control of maintenance and cleaning procedures of the red wine bottling line. oPRP 10.3 Control of the correct coding of the labels used on the bottles. oPRP 10.4 Control of correct allergen information on labels used on bottles. CCP 10.1 Microbiological control of the bottling line of red wine and bottles. CCP 10.2 Microbiological control of the cork stopper or similar used for closing the bottles.

rigorous testing, serve to validate the efficacy of CCPs, with swift corrective actions promptly implemented upon detecting any contamination. Meticulous documentation and comprehensive record-keeping throughout the entire HACCP process stand as imperative requirements for ensuring adherence to regulatory standards and facilitating traceability.

A critical control point (CCP) is a point in a step or procedure at which a control must be applied and is essential to prevent or eliminate a food safety hazard or reduce it to an acceptable level [1]. Conducting a hazard analysis of CCPs enables the identification, evaluation, and control of significant CCPs throughout the food production process. Once potential hazards are identified, their status as a CCP is assessed, and reference limits or critical limits are established through the implementation of preventive measures to prevent deviations from these limits [13,16,19]. Identification of CCPs is executed by employing the decision tree framework as outlined by Codex Alimentarius, which was further tailored with ISO 22000: 2018 (E) criteria [20]. This procedure helps determine whether the hazards can be effectively addressed as Operational Prerequisite Programme (oPRPs) or whether specific operational protocols, including defined measures, are required for the management of CCPs [20,21]. Inadequate control of CCPs can lead to contamination of grapes and wines with microorganisms, residues from phytosanitary products, or traces of heavy metal or metalloids from soils.

Christaki, T. (2002) identified main CCPs in red wine production [22]. Benito, S. (2019) conducted a study on the identification and control of CCPs during winemaking to mitigate the levels of various compounds, including biogenic amines, ethyl carbamate, ochratoxin A, and sulfur dioxide [23]. Martinez-Rodriguez (2009) studied CCPs associated with microbial safety during wine production, with a particular focus on Ochratoxin A [24].

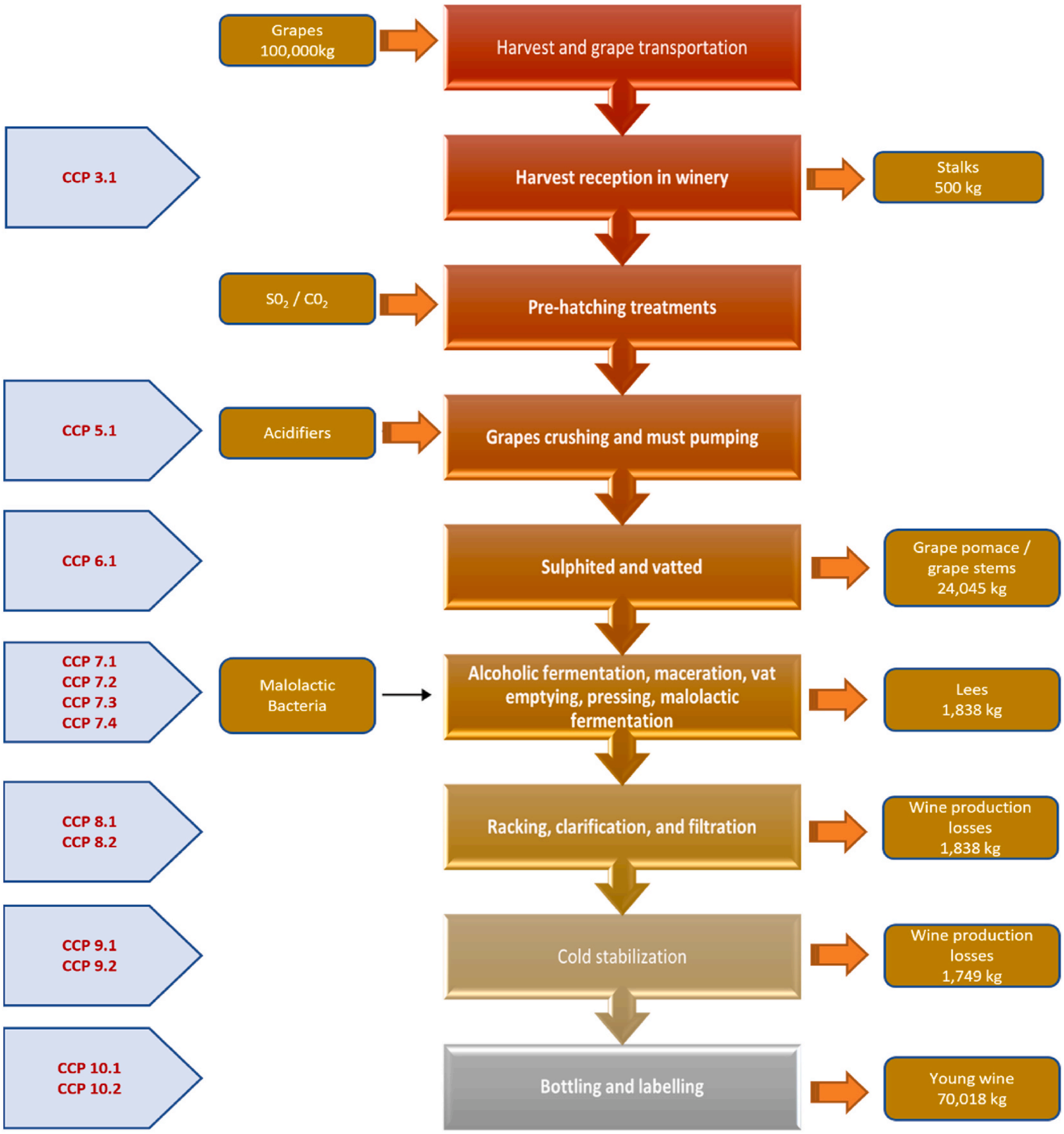

Fig. 1. Flow diagram of the young wine making process and corresponding CCPs to each stage of this process.

Table 1 shows main CCPs and oPRPs in the production of young wine based on previous research [20,22–25]. Fig. 1 shows a flow diagram of wine-making process and corresponding CCPs to each stage of this process based on technical document [26] and Table 1.

Lopez-Santiago (2022) demonstrated that the presence of traces of heavy metals and metalloids in grapes and wines were inadequately controlled CCPs in wineries [27].

These metals and metalloids contamination hazards correspond to CCP 3.1, which involves controlling the presence of metals and metalloids (Cd, Pb, As) in grapes at the Harvest reception stage in the winery, and CCP 9.1, which focuses on controlling the limit concentrations of metals (traces of As, Cu, Pb) in red wine during the Cold stabilization stage in the flow diagram of the young wine-making process as shown in Fig. 1.

According to Lopez-Santiago, fifty percent of the wineries exhibited a complete lack of control over the contamination hazards of arsenic, lead and cadmium in grapes and wines [27].

Herce-Pagliai determined that the concentration of arsenic in Spanish wines ranged from 2.1 to 14.6 μg/L, and the average total arsenic concentration was similar across all wine samples [28]. A review study by the Organisation Internationale de la Vigne et du Vin (OIV) showed that Spanish wines consistently comply with lead concentration limits. The study analyzed sixty-five white and red wines obtaining that lead concentration was below 0.05 mg/L [29].

International and national regulations establish maximum allowable levels of heavy metals and metalloids in grapes and wines to prevent toxicity issues for consumers. The European legislative framework sets maximum permitted concentrations levels for arsenic, lead and cadmium, along with guidelines for monitoring these levels [30–34]. According to OIV, the maximum acceptable limits for certain metals in wine are 0.2 mg/L for arsenic, 0.01 mg/L for cadmium, 0.15 mg/L for lead [35]. German legislation sets 0.1 mg/L for arsenic, 0.01 mg/L for cadmium, and 0.3 mg/L for lead, while Italian legislation sets it at 0.3 mg/L [36].

The control of metals and metalloids in grapes and wines is achieved through analytical methods recommended by the OIV, primarily based on atomic absorption spectrometry due to its selectivity, sensitivity, and ability to directly measure these elements. Graphite furnace atomic absorption spectrometry (GFAAS) or electrothermal atomization (ETAAS) are used for arsenic, cadmium, and lead analysis. GFAAS allows detection limits to be lowered to the parts per billion (ppb) range with relative simplicity and eliminating the need for prior extraction techniques [37]. Table 2 presents the OIV recommended methods for determining Arsenic [38], Cadmium [39] and Lead [40] in wines and must.

Within this framework, the primary aim of this research is to assess the effectiveness of wineries in managing Critical Control Points (CCPs) associated with contamination risks posed by arsenic, cadmium, and lead in grapes and wines. Additionally, the study aims to develop a methodology for evaluating their advancement, incorporating the use of performance indicators within the HACCP plan to highlight the element of training as a corrective action. Furthermore, the study aims to identify the challenges that impede achieving adequate control.

Table 2
International methods to determine arsenic, cadmium, and lead in wines and must recommended by the OIV.

Element	Method	Summary
Arsenic	OIV-MA-AS323-01A Determination of arsenic in wine by atomic absorption spectrometer	This method is a recommended procedure for the determination of arsenic in wine using GFAAS and hydride generation. The equipment required includes glassware, a water bath, filters, and a spectrophotometer with specific instrumental parameters. Various reagents such as nitric acid, potassium iodide, hydrochloric acid, sodium borohydride, and sodium hydroxide are used. Calibration standards are prepared, and the sample preparation involves evaporation, addition of potassium iodide and hydrochloric acid, and filtration. The determination is performed by introducing the borohydride solution, hydrochloric acid solution, and sample solution into the peristaltic pump. Calibration standards and samples are analyzed, and the software establishes the arsenic concentration. Quality control is maintained by including control samples from the Bureau Communautaire de Référence.
Cadmium	OIV-MA-AS322-10 Determination of arsenic in wine by atomic absorption spectrometer	This method is a recommended procedure for the direct determination of cadmium in wine using atomic absorption spectrometer. The apparatus required includes an atomic absorption spectrophotometer with a graphite furnace, background correction, and a recorder, as well as specific glassware and a cadmium hollow cathode lamp. Various reagents, including phosphoric acid, ethylenediamine tetra-acetic acid solution, buffer solution, and Eriochrome black T, are used in the analysis. The concentration of cadmium sulfate is verified through titration with ethylenediamine tetra-acetic acid solution. The procedure involves sample preparation, preparation of calibration standards, and determination using specific furnace programming and atomic absorption measurements. The results are expressed as the concentration of cadmium in micrograms per liter of wine.
Lead	OIV-MA-F1-10 Specific methods Type IV method Annex D: Heavy metals D.1 Determination of lead level by Electrothermal Atomic Absorption Spectrophotometry	This is an ETAAS technique for determining lead levels in grape sugar samples. It provides instructions on reagents, equipment, calibration, safety precautions, and sampling. The method covers a lead concentration range of 10 μg/kg to 200 μg/kg. The use of lead-free reagents is emphasized, and calibration curves are used to calculate lead concentrations. The apparatus required includes an atomic absorption spectrometer with specific settings. The specific settings for the ETAAS method include using an electrothermal atomizer, a hollow-cathode lamp for lead, a background noise correction device, and adjusting temperature and gas flow rates for optimal measurement range and sensitivity. Zeeman background noise correction is preferred to reduce interference. Precision parameters for repeatability and reproducibility are provided for lead concentrations below 150 μg/kg.

2. Materials and methods

2.1. Study design

The research study design was proposed by conducting a survey and its later analysis using right statistical methods. The sample was selected among Spanish wineries from different wine regions. During last half of 2022, the survey was conducted, and then, SPSS Windows software SPSS was used to analyse the data (IBM Corp. Released 2020. IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY, USA: IBM Corp.). The calculated statistics were frequencies and central position values. Non-parametric tests were estimated obtaining Spearman correlation coefficient (ρ) and Kendall's Tau coefficient (τ) for nonparametric data, with a significance level of $p < 0.01$. Non-parametric Mann-Whitney *U* Test for two independent samples were applied, with a significance level of $p < 0.05$.

2.2. Sample selection

Spain had approximately 4133 wineries in 2020 [41] and one hundred and one Wine Protected Designation of Origin (WPDO) [42]. One hundred-thirty-nine wineries were selected from different WPDOs for this research. The sampling methodology selected was the non-probabilistic method [43,44]. Researchers used previous information to make the sample selection, instead of random selection [45]. The criteria for configuring the sample were that there was diversity in wineries′ sizes according to their annual wine production, wineries must belong to a WPDO, and has been HACCP implemented. Wineries were asked about their performance in controlling the risk of arsenic, lead, and cadmium contamination critical control point in the winemaking.

The questionnaire was sent twice to all the wineries in the sample, and additionally, the questionnaire was sent once again to fifty of them through the 'Contact' section of their website. Thirty-two wineries answered the questionnaire, which represents 23 % of the wineries sampled.

2.3. Survey preparation

The survey design consisted of a questionnaire divided into four sections, with a total of fifteen closed-ended questions. The questions were developed based on previous research studies [2,3,10,19,29,46,47]. The questionnaire can be found in Appendix A. This type of questionnaire is commonly used in causal, descriptive, and conclusive research [48]. Fig. 2 illustrates the questionnaire structure, including the contents of each section, and the questions and variables in each section.

Question G.1 determined winery size based on yearly wine production and assigned winery groups to cover all responses. Questions G.2 and G.3 are dichotomous (yes/no) questions about PPR and HACCP implementation and, Question G.4 inquired about the number of winery staff.

Question G.5 focused on the number of workers trained in Good Manufacturing Practices (GMP). It utilized a qualitative scale and a quantitative variable represented by a Likert scale (ranging from 0.33 to 1). Variable V_{G5} indicated the level of GMP training among workers, with values of 0.33 representing "No workers have GMP training," 0.66 representing "More than half of workers have GMP training," and 1 representing "All workers have GMP training."

Similarly, question G.6 asked about the number of workers trained in the control and monitoring of CCPs. It also utilized a

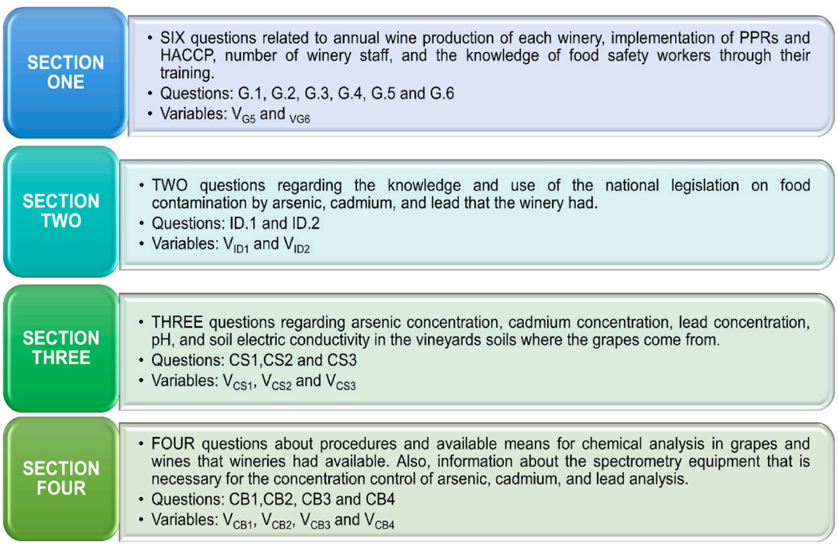

Fig. 2. Structure of the questionnaire that encompassing four sections with its specific content.

qualitative scale and a quantitative variable represented by a Likert scale (ranging from 0.33 to 1). Variable V_{G6} indicated the level of workers trained in CCPs, with values of 0.33 representing "No workers have training in control and monitoring of CCPs," 0.66 representing "More than half of workers have training in control and monitoring of CCPs," and 1 representing "All workers have training in control and monitoring of CCPs."

Question ID.1 was a multiple-choice question assessing winery performance in identifying legislation related to arsenic, cadmium, and lead. It was coded using a Likert scale, with the variable V_{ID1} (ranging from 0.33 to 1) representing winery performance regarding legislation identification. Question ID.2 was a dichotomous (yes/no) question asking about winery identification of updated information from the Spanish Agency for Food Safety and Nutrition (AESAN) on heavy metals and metalloids food risk. Variable V_{ID2} took values of 0 for "No" and 1 for "Yes."

Question CS1 was a dichotomous (yes/no) question about winery information regarding vineyard soil physical and chemical analysis. Variable V_{CS1} took values of 0 for "No" and 1 for "Yes." Question CS2 was a dichotomous (yes/no) question about winery information regarding fertilizer use in vineyard soils. Variable V_{CS2} took values of 0 for "No" and 1 for "Yes." Question CS3 was a multiple-choice question with eight options regarding winery information on soil chemical properties. Variable V_{CS3} calculated the cumulative value (0.125) assigned to each selected option, indicating the level of winery knowledge regarding specific soil chemical properties.

Question V_{CB1} was a dichotomous (yes/no) question about whether the winery had its own laboratory for chemical analyses. Variable V_{CB1} took values of 0 for "No" and 1 for "Yes." Question C_{B2} was a dichotomous (yes/no) question about whether the winery used an external laboratory for chemical analyses. Variable V_{CB2} took values of 0 for "No" and 1 for "Yes." Question CB3 was a dichotomous (yes/no) question about whether the winery had its own atomic absorption spectrometer and staff for metal analyses. Variable V_{CB3} took values of 0 for "No" and 1 for "Yes''. Question CB4 was a dichotomous (yes/no) question about whether the winery used an external laboratory for metal trace analyses. Variable V_{CB4} took values of 0 for "No" and 1 for "Yes''. Finally, there was a multiple-choice question about the job position of the survey respondent.

We have formulated three hypotheses to be examined in this study. Hypothesis one (H1) proposed that workers who received adequate GMP and CCP training demonstrate a satisfactory performance level of CCP controlling in the wineries. Hypothesis two (H2) stated that legislation performance component regarding to its identification and updating about the contamination risk posed by arsenic, cadmium, and lead has reached a mature level in the wineries. Hypothesis three (H3) proposed that wineries possess information about the concentrations of arsenic, cadmium, and lead in the vineyard soils from which grapes (raw material) are harvested and that wineries have adequate spectrometric equipment for their identification.

3. Results

Fig. 3 shows the wineries distribution in five groups according to their answers about their yearly wine production.

Regarding the FSMS implementation, 96.9 % of the wineries had implemented PRPs according to food hygiene legislation, and a 93.8 % of the wineries had implemented a HACCP.

3.1. Performance of wineries in relation to food safety training component

Table 3 shows the results for the percentage of workers trained in good manufacturing practices in winemaking (GMP), the percentage of workers trained in the monitoring and CCPs, and number of workers median and arithmetic mean by type of winery. All workers in wineries with annual production over 250,001 L/year have received GMP training and all workers in wineries with annual

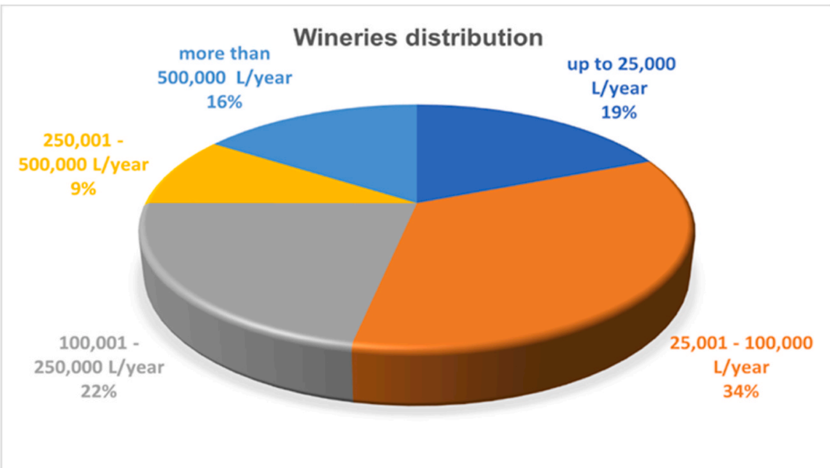

Fig. 3. Wineries sample distribution according to their yearly wine production (L/year).

Table 3
GMP workers training and CCPs workers training by type of winery.

Wine Annual Production L/year	Percentage of Wineries Over Total	GMP Workers training (%)			CCPs Workers training (%)			Number of workers	
		All	More Than 50 %	None	All	More than 50 %	None	Median	Arithmetic mean
up to 25,000	18.8	66.7	33.3	0.0	66.7	33.3	0.0	2.5	2.3
25,001–100,000	34.4	60.0	20.0	20.0	40.0	50.0	10,0	4.0	3.3
100,001–250,000	21.9	28.6	57.1	14.3	28.6	57.1	14.3	5.0	5.1
250,001–500,000	9.4	100.0	0.0	0.0	66.7	33.3	0.0	7.0	7.3
more than 500,000	15.6	100.0	0.0	0.0	100.0	0.0	0.0	10.0	21.7
Total wineries Percentage	100.0	65.6	21.9	12.5	53.1	37.5	9.4	4.0	6.1

production over 500,000 L/year have received CCPs training. Although some wineries producing between 25,001–250,000 L/year have all workers without GMP or CCPs training, it can be said that most of the wineries have some GMP-trained and CCPs-trained workers.

Spearman correlation coefficient (ρ) is 0.686 and Kendall's Tau coefficient (τ) is 0.653 between variables V_{G5} and V_{G6}. It shows there is a positive correlation between the GMP Workers Training and CCPs Workers Training.

Results show that as the winery gets bigger according to its yearly wine production, it has more workers trained in GMP and CCPs. However, the percentage of trained workers is also high in smaller wineries. This is due to the number of workers ranging between two and three in this winery group, and therefore having trained a worker already reaches values of fifty percent. This finding is in agreement with the study conducted by Lee J.C. et al. [49], which identified significant increases in the application of GMP, GHP, and equipment design prerequisites, as well as all HACCP systems, in European companies.

In general, wineries train a higher percentage of workers in GMP than in CCPs. One in two wineries has half of its workers untrained in CCPs. This is a difficulty for identification and control of CCP related to the risk of contamination by arsenic, cadmium, and lead during the winemaking process. Wineries that supply training to their workers do so in both GMP and CCPs.

A quantitative analysis of food safety worker training (FSWT) was performed based on an indicator defined by equation (1) [50,51]:

$$W_{fswt} = (V_{G5} + V_{G6}) / n \tag{1}$$

Where.

- W_{fswt} is aggregated FSWT variable for each winery,
- V_{G5} is variable that stands for the level of workers trained in GMP, and takes values 0.33, 0.66 or 1.
- V_{G6} is variable that represent level of workers trained in CCP, and takes values 0.33, 0.66 or 1.
- n is number of variables that has been aggregated, and its value is 2.

Obtaining FSWT Indicator (I_{fswt}) for each group of wineries according to their yearly wine production size by equation (2):

$$I_{fswt} = \frac{\sum_{i=1}^{m} W_{fswt}}{m} \tag{2}$$

Where.

- I_{fswt} is FSWT Indicator for each group of wineries according to yearly wine production,
- W_{fswt} is FSWT variable for each winery,
- m is number of wineries of related group.

Table 4
Heavy Metal Food Contamination Risk (HMFCR) legislation identification and HMFCR legislation updating through National Agency (AESAN) by type of winery.

Wine Annual Production L/year	Percentage of Wineries Over Total	HMFCR legislation identification (%)				HMFCR Legislation updating through AESAN (%)	
		As	Cd	Pb	None	Yes	No
up to 25,000	18.8	33.3	33.3	50.0	50.0	50.0	50.0
25,001–100,000	34.4	33.3	33.3	33.3	66.7	33.3	66.7
100,001–250,000	21.9	28.6	28.6	28.6	71.4	28.6	71.4
250,001–500,000	9.4	66.7	66.7	66.7	33.3	66.7	33.3
more than 500,000	15.6	66.7	66.7	66.7	33.3	66.7	33.3
Total wineries Percentage	**100.0**	**31.2**	**31.2**	**37.5**	**62.5**	**37.5**	**62.5**

This indicator is dimensionless and expresses the grade of progress achieved regarding food safety worker training in each of the winery groups, according to their annual production. The grades of progress are defined as Star (I_{fswt} between 0 and 0.33), In progress (I_{fswt} between 0.34 and 0.67), and Maturity (I_{fswt} between 0.67 and 1). I_{fswt} values for winery size group regarding to their annual wine production are showed in Table 6.

3.2. Performance of wineries in relation to heavy metal and metalloids food contamination risk legislation component

Second section results are collected in Table 4. This table shows the heavy metal and metalloids food contamination risk (HMFCR) legislation identification and HMFCR legislation updating the through National Agency (AESAN) by type of winery.

There is a low wineries percentage that have identified arsenic, cadmium, and lead contamination risk legislation. Rates are higher in wineries with wine production over 250,000 L/year. In this case, two out of three wineries have identified arsenic, cadmium, and lead legislation. Wineries between 100,001–250,001 have the lowest rate (28.6 %).

National Agency thar integrates and performs the functions related to food safety within the competence framework of the General Administration of Spain is the Agencia Española de Seguridad Alimentaria y Nutrición (AESAN) [52]. Information on applicable arsenic, cadmium and lead contamination food risks legislation is available and updated on the AESAN website [53]. AESAN information is used by only one-third of small to medium-sized wineries (up to 250,000 L/year). information. Bigger wineries (over 250, 001 L/year) have a better rate (66.7 %), but it is still insufficient. HMFCR legislation is not clearly identified in wineries, and this occurs especially in wineries with annual wine production under 250,001 L/year. The Spearman correlation coefficient (ρ) is 0.894 and Kendall's Tau coefficient (τ) is 0.873 between variables V_{ID1} and V_{ID2}. It shows there is a strong positive relationship between the identification of HMFCR legislation and it is and updating through AESAN. Besides, correlation coefficients have been calculated for V_{ID1} and V_{ID2}. The Spearman correlation coefficient (ρ) is 0.413 and Kendall's Tau coefficient (τ) is 0.393. A positive correlation exists between the workers′ CCPs training and the HMFCR legislation identification in the wineries.

A quantitative analysis of legislation identification and updating (LIU) was performed based on an indicator defined by equation (3):

$$W_{liu} = (V_{ID1} + V_{ID2}) / n \quad (3)$$

Where.

- W_{liu} is aggregated LIU variable for each winery,
- V_{ID1} is variable that stands for winery performance about legislation identification about arsenic, cadmium, and lead, and takes values 0.33, 0.66 or 1.
- V_{ID2} is variable that represented winery performance about update legislation information through AESAN and takes values 0 or 1.
- n is number of variables that has been aggregated, and its value is 2.

Obtaining LIU Indicator (I_{liu}) for each group of wineries according to their yearly wine production size by equation (4):

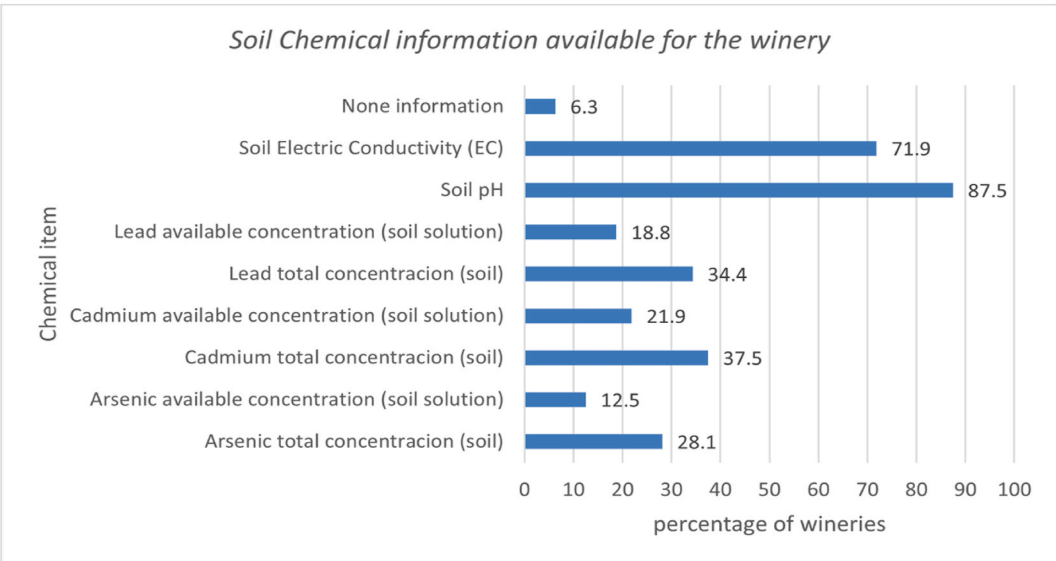

Fig. 4. Percentage of wineries that have information related to the soil chemical analysis of the vineyards regarding to arsenic, cadmium and lead concentrations, Soil pH, and EC.

$$I_{liu} = \frac{\sum_{i=1}^{m} W_{liu}}{m} \quad (4)$$

Where.

- I_{liu} is LIU Indicator for each group of wineries according to yearly wine production,
- W_{liu} is LIU variable for each winery,
- m is number of wineries of related group.

This indicator is dimensionless and expresses the grade of progress achieved regarding the analysis of legislation identification and updating in each of the winery groups, according to their annual production. The grades of progress are defined as Star (I_{liu} between 0 and 0.33), In progress (I_{liu} between 0.34 and 0.67), and Maturity (I_{liu} between 0.67 and 1). I_{liu} values for winery size group regarding to their yearly annual wine production are showed in Table 6.

3.3. Performance of wineries in relation to chemical analysis of the vineyards regarding to arsenic, cadmium, and lead

Most wineries have data about vineyard soils′ physical and chemical analysis, and fertilizer information used in the vineyard soils. Spearman correlation coefficient (ρ) between V_{CS1} and V_{CS2} is 0.686. This positive correlation demonstrates that wineries that possess information about the physical and chemical analysis of vineyard soil tend to also have information about the fertilizers used in those vineyard soils.

The percentage of wineries that have information related to the soil chemical analysis of the vineyards where the grapes come from shown in Fig. 4.

However, this information is mostly about soil pH (87.5 %) and soil electric conductivity (71.9 %). The number of wineries that have chemical information about arsenic, cadmium, and lead concentrations decreases considerably. Table 5 shows data on the percentage of wineries, segmented according to their level of annual wine production, which have information regarding arsenic, cadmium, and lead total/available concentrations.

One out of every three wineries possess data regarding the cumulative levels of arsenic, cadmium, and lead concentrations in the soil. Besides, wineries percentage decreases when the information is about soil solution concentrations of arsenic, cadmium, and lead. Hence, one in ten possesses data concerning the presence of arsenic in vineyard soils, while two in ten wineries have information pertaining to the concentrations of cadmium and lead in the same soil samples.

Information data about total cadmium and lead concentrations are the ones that most have the wineries, especially the largest wineries (over 250,001 L/year). Instead of the information about total arsenic concentration, it says that it is an extremely low percentage in all winery groups. The percentages of wineries relating to the information about the concentrations of arsenic, cadmium, and lead in the soil solution are lower those relating to the total concentration. It is the information related to the concentration of cadmium available in the soil solution that presents the highest percentage, being 66.7 in the wineries between 250,001–500,000 L/year and 28.6 in the wineries between 100,001–250,000 L/year. The lack of information on arsenic, cadmium, and lead soil concentrations is a difficulty for the CCP controlling as it impedes an adequate assessment of the risk that grapes used for winemaking may have been contaminated during cultivation or harvest.

A high percentage of wineries (78.1 %) have their own laboratory in their facilities to make chemical analyses of grapes and wines. Two out of every ten wineries do not have their own laboratory. In this case, most of them (92.3 %) use an external laboratory service to make chemical analyses of grapes and wines. In this context, control of arsenic, cadmium, and lead in grapes and wines is made by analytical techniques based on atomic absorption spectrometry. Only one out of every ten wineries possess the necessary technological equipment and qualified staff capable of conducting heavy metal analysis using atomic absorption spectrometry. A high percentage of wineries (93.8 %) do not have them. Thirty-five-point-two percent of wineries without atomic absorption spectrometry equipment and qualified staff use external laboratories to analyse about heavy metals and metalloids concentration in grapes and wines. This result shows that the lack of technical means for qualitative and quantitative analysis in wineries is a barrier to good performance related to controlling arsenic, cadmium and lead contamination risk in grapes and win es.

Table 5
of wineries that have information related to the soil chemical analysis of the vineyards regarding to arsenic, cadmium, and lead concentrations, by type of winery.

Wine Annual Production L/year	Percentage of Wineries Over Total	Total concentration (soil) (%)			Available concentration (Soil solution) (%)			None
		As	Cd	Pb	As	Cd	Pb	
up to 25,000	18.8	33.3	16.6	16.6	0.0	0.0	0.0	0.0
25,001–100,000	34.4	18.2	27.3	27.3	18.2	27.3	27.3	9.1
100,001–250,000	21.9	14.3	42.9	28.6	0.0	28.6	14.3	0.0
250,001–500,000	9.4	33.3	66.7	66.7	33.3	66.7	66.7	0.0
more than 500,000	15.6	40.0	40.0	40.0	0.0	0.0	0.0	40.0
Total wineries Percentage	**100.0**	**28.1**	**37.5**	**34.4**	**12.5**	**21.9**	**18.8**	**6.3**

Table 6
Wineries performance indicators and grade of progress, by type of winery.

Wineries size	I_{fswt}	Grade of progress	I_{liu}	Grade of progress	$I_{ccp-Mchem}$	Grade of progress
Up to 25,000 L/year	0.89	Maturity	0.44	In progress	0.05	Start
25,001–100,000 L/year	0.77	Maturity	0,15	Start	0.08	Start
100,001–250,000 L/year	0.78	Maturity	0.28	Start	0.51	In progress
250,001–1,000,000 L/year	0.94	Maturity	0.66	In progress	0.56	In progress
More than 500,000 L/year	0.93	Maturity	0.60	In progress	0.42	In progress

A quantitative analysis of arsenic, cadmium, and lead critical control point chemical analysis performance (CCP-MCHEM) was evaluated based on an indicator defined by equation (5):

$$W_{ccp-Mchem} = \left(V_{CS3} + V_{CBrx} + V_{CBry}\right) \Big/ n \tag{5}$$

Where.

- $W_{ccp-Mchem}$ is the aggregated CCP-MCHEM variable for each winery,
- V_{CS3} is variable that stood for chemical information about arsenic, cadmium, and lead concentrations in soil that winery had. $V_{CS3} = \sum_{j=1}^{8} a_j$, a_j is each item of this multiple-choice question (yes = 0.125, no = 0),
- V_{CBrx} is variable that represented winery capacity to hold chemical analysis by their own or external means. $V_{CBrx} = V_{CB2}$ if $V_{CB1} = 0$, otherwise $V_{CBrx} = V_{CB1}$.
- V_{CBry} is variable that stood for winery capacity to hold arsenic, cadmium and lead chemical analysis by their own or external means. $V_{CBry} = V_{CB4}$ if $V_{CB3} = 0$, otherwise $V_{CBry} = V_{CB3}$.
- n is the number of variables that has been aggregated, and its value is 3.

Table 7
Relationship questions among wineries performance variables, their imply variables and MWU results.

Question	Variables	Non-parametric Mann-Whitney *U* Test	Result
Did grade of progress of training component differ according to whether wineries conducted identification and updating arsenic, cadmium, and lead contamination risk legislation available in AESAN or did not?	W_{fswt} as a dependent variable V_{ID2} as an independent variable which stood for two groups ($V_{ID2} = 0$, $V_{ID2} = 1$).	$Z = -2.673$ Bilateral significance = 0.008 Exact significance = 0.013 Monte Carlo significance = 0.009, lower limit = 0.007, upper limit = 0.011 $p < 0.05$	Rejected hypothesis null. (Differed)
Did grade of progress of training component differ according to wineries capacity to do arsenic, cadmium and lead chemical analysis by their own or external means or did not?	W_{fswt} as a dependent variable V_{CBry} as an independent variable which stood for two groups ($V_{CBry} = 0$, $V_{CBry} = 1$).	$Z = -0.555$ Bilateral significance = 0.579 Exact significance = 0.616 Monte Carlo significance = 0.598, lower limit = 0.598, upper limit = 0.607 $p < 0.05$	Accepted hypothesis null. (Did not differ)
Did grade of progress of the legislation component differ according to wineries capacity to do arsenic, cadmium and lead chemical analysis by their own or external means or did not?	W_{liu} as a dependent variable V_{CBry} as an independent variable which stood for two groups ($V_{CBry} = 0$, $V_{CBry} = 1$).	$Z = -2.506$ Bilateral signature = 0.012 Exact signature = 0.029 Monte Carlo significance = 0.013, lower limit = 0.011, upper limit = 0.016 $p < 0.05$	Rejected hypothesis null. (Differed)
Did grade of progress of the legislation component differ according to whether wineries conducted identification and updating arsenic, cadmium, and lead contamination risk legislation available in AESAN or did not?	W_{liu} as a dependent variable V_{ID2} as an independent variable which stood for two groups ($V_{ID2} = 0$, $V_{ID2} = 1$).	$Z = -5.355$ Bilateral signature = 0.001 Exact signature = 0.001 Monte Carlo significance = 0.000, lower limit = 0.000, upper limit = 0.000 $p < 0.05$	Rejected hypothesis null. (Differed)
Did grade of progress of the analysis component differ according if winery had information related to vineyards soil physical and chemical analysis or did not?	$W_{ccp-Mchem}$ as a dependent variable V_{CS1} as an independent variable which stood for two groups ($V_{CS1} = 0$, $V_{CS1} = 1$).	$Z = -3.288$ Bilateral signature = 0.001 Exact signature = 0.001 Monte Carlo significance = 0.000, lower limit = 0.000, upper limit = 0.000 $p < 0.05$	Rejected hypothesis null. (Differed)
Did grade of progress of the analysis component differ according if winery had fertilizer information used in vineyard soils or did not?	$W_{ccp-Mchem}$ as a dependent variable V_{CS2} as an independent variable which stood for two groups ($V_{CS2} = 0$, $V_{CS2} = 1$).	$Z = -3.288$ Bilateral signature = 0.001 Exact signature = 0.001 Monte Carlo significance = 0.000, lower limit = 0.000, upper limit = 0.000 $p < 0.05$	Rejected hypothesis null. (Differed)

Obtaining CCP-MCHEM Indicator ($I_{ccp-Mchem}$) for each group of wineries according to their yearly wine production size by equation (6):

$$I_{ccp-Mchem} = \frac{\sum_{i=1}^{m} W_{ccp-Mchem}}{m} \quad (6)$$

Where.

- $I_{ccp-Mchem}$ is CCP-MCHEM Indicator for each group of wineries according to yearly wine production,
- $W_{ccp-Mchem}$ is CCP-MCHEM variable for each winery,
- m is number of wineries of related group.

This indicator is dimensionless and expresses the grade of progress achieved regarding to arsenic, cadmium, and lead critical control point chemical analysis performance in each of the winery groups, according to their annual production. The grades of progress are defined as Star ($I_{ccp-Mchem}$ between 0 and 0.33), In progress ($I_{ccp-Mchem}$ between 0.34 and 0.67), and Maturity ($I_{ccp-Mchem}$ between 0.67 and 1). $I_{ccp-Mchem}$ values for winery size group regarding to their annual wine production are showed in Table 7.

3.4. Matrix and graph of the grade of progress in wineries generated by the performance indicators

The three performance indicators allow to determine the degree of progress that each group of wineries has reached related to the control that they conduct on the contamination risk of arsenic, cadmium, and lead in grapes and wines. Table 6 shows values I_{fswt}, I_{liu} and $I_{ccp\text{-}Mchem}$ by winery sizes groups and grade of progress.

Effectiveness in conducting risk control is divided into three components: the training component, the legislation component, and the analysis component.

Each indicator stands for the degree of progress on a component. $\boldsymbol{I_{fswt}}$ is performance indicator that shows progress in the training component. $\boldsymbol{I_{liu}}$ is the indicator that shows progress in the legislation component and $\boldsymbol{I_{ccp-Mchem}}$ is the indicator that shows progress in analysis component. Components performance level by each winery sizes group on the contamination risk by arsenic, cadmium and lead in grapes and wines in Fig. 5.

Training is the component with the greatest maturity while analysis is the component with the least maturity regarding to this contamination risk control. Wineries below 250,000 L/year are in the starting performance level of the analysis component, and wineries between 25,001 and 250,000 L/year are in the starting performance level of the legislation component.

Non-parametric Mann-Whitney U Tests (MWU) were applied to find relationships among wineries performance variables. Table 7 shows relationship questions, their imply variables and MWU results. Grade of progress of training component differed according to whether wineries conducted identification and updating the legislation related to risk of arsenic, cadmium, and lead contamination available in AESAN, but it was not different regarding to whether wineries had capacity to do arsenic, cadmium and lead chemical analysis by any means.

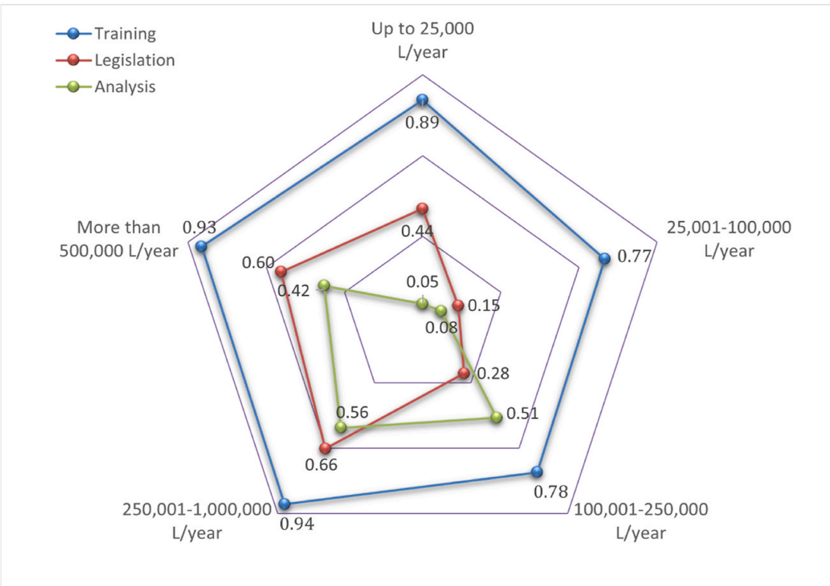

Fig. 5. Performance level in each component by annual winery production.

Grade of progress of the legislation component was different according whether wineries had capacity to do arsenic, cadmium and lead chemical analysis by any means and differed regarding to if wineries conducted identification and updating arsenic, cadmium, and lead contamination risk legislation available in AESAN or did not.

Grade of progress of the analysis component differed according if winery had information regarding to vineyards soil physical-chemical analysis and, according to if winery had fertilizer information used in vineyard soils or had not.

4. Discussion

An evaluation of how wineries are managing critical control point about controlling the contamination risk by arsenic, cadmium and lead in their winemaking processes is essential to prevent poisoning and diseases in consumers. Studies have identified health problems caused by As, Cd, and Pb [54,55].

Fertilizers or the environment are sources of arsenic, cadmium and lead that can contaminate grapes and wines used in wine production [9,55,56].

4.1. GMP and CCP workers training

FSMS are tools to accomplish with food hazards control as heavy metals and metalloids traces in grapes and wines. There is an important level of implementation of FSMS in wineries. 96.9 % of wineries have a Prerequisites Programmes and 93.8 % have HACCP. Besides, workers trained in GMP and CCPs have a satisfactory level for all wineries.

The study reveals that hypothesis 1 (H1) is true. The training component has reached an adequate maturity level of performance. 65.6 % of wineries have all their workers trained in GMP and 53.1 % of wineries have all their workers trained in CCPs. These percentages arise to 100 % in wineries with annual production over 500,001 L/year. Results show that wineries′ workers who receive training in GMP, also receive training in CCPs. Similarly, other related studies focusing on controlling OTA mycotoxin contamination in wines have also demonstrated that training in GMP and CCPs has been identified as a significant contributing factor to the successful prevention of such contamination [24]. Our findings are consistent with the research conducted by Lee, J.C. et al. [49], wherein the importance of aspects related to food safety culture is underscored, particularly about human factors and specialized training.

4.2. Knowledge and application of food safety legislation

Hypothesis 2 (H2) is not fulfilled. Legislation component is still in progress level regarding performance maturity in four up five wineries groups. European legislation on food safety related to contamination control risk from arsenic, cadmium and lead is accessible. Study shows that only one out three wineries with annual production less than 250,000 L/year has identified and updated the HMCR legislation. The HCMR legislation identification percentage is 66.7 % in wineries with annual production over 250,001 L/year. Two out of three wineries that have the HCMR legislation identified conduct its update through the information available in the Food Safety Spanish Agency (AESAN). Mere publication of food risk information on the AESAN website is not enough for wineries to incorporate it into their control system. Two out of three wineries do not have updated legislation and do not use the information provided by AESAN.

Most of the wineries that have identified the HCMR legislation, also have their staff trained in CCPs. Identification of food risk control legislation is different according to the wine production level of the wineries and their workers′ knowledge. The public administration does not provide sufficient references and means for wineries to properly develop and implement the control of CCP related to the risk contamination of arsenic, cadmium, and lead. Our result is aligned with Vela A.R. & Fernández [56], that demonstrated public administrations received a low score from companies regarding to the references provided by the administration (reports, books, and articles) to facilitate the development and implementation of FSMS. Matches with the alcoholic beverage industry's weakness in compliance with food safety legislation demonstrated by Kourtis L.K [57].

Charlotte Yap [58] found that knowledge about the general principles of food safety and its requirements is low in small and medium-sized agrifood businesses. This often leads to regulatory requirements being underestimated and not considered. This lack of knowledge regarding the risk of heavy metal and metalloid contamination in food is a weakness observed in wineries' control over their winemaking processes.

Our findings also align with the study conducted by Allam, M. et al. [59], which identified areas where organic food producers and processors in several European countries require further guidance and support in food safety, particularly in their proficiency in performing hazard analysis and creating documents and records following HACCP principles.

4.3. Analysis and availability of chemical data related to the control of contamination by As, Cd, and Pb

Hypothesis 3 (H3) is not accomplished. Analysis is the lower performance component for all winery groups, except 100,000 to 250,000 L/year. We found that many wineries have not information about arsenic, cadmium, and lead concentrations in the vineyards soils, and the wineries percentage that owns this information is different according to their wine annual production level. Nine of ten wineries have information about soil physical and chemical characteristics, such as pH and EC, and information about the fertilizers used in the vineyards. However, these values strongly decrease about the arsenic, cadmium, and lead concentrations in these soils. The proportion of wineries equipped with data on the cumulative concentrations of arsenic, cadmium, and lead is remarkably low. However, these percentages become even more diminished when considering the availability of information concerning specific arsenic, cadmium, and lead available concentrations in the soil. Out of the ten wineries, two wineries have this chemical concentration information about cadmium and lead, and one winery has this chemical concentration information about arsenic. A deficient control of these the arsenic, cadmium, and lead in soils implies that food hazards as the appearance of heavy metal traces in grapes or wine may occur [60,61]. The wineries use techniques based on atomic absorption spectrometry for the identification of the arsenic, cadmium, and lead in the grapes and wines. This technique is recommended by the OIV. However, there is a lack of this spectrometry equipment in the wineries own laboratories, so they need to use external analytical services. Results show that half of the wineries (48.59 %) use atomic absorption spectrometry analysis to detect the presence of arsenic, cadmium, and lead in the grapes and wines through external analytical services. Courtney K. Tanabe (2019) identified the absence of on-site chemical analytical tools as a factor that influences the arsenic content in grapes and wines [62].

4.4. Limitation and strength of the study

One of the principal weaknesses of this study lies in the low response rate obtained from the surveyed wineries, potentially impacting the representativeness and generalizability of the data to the entire wine industry. However, a fundamental strength of this research is rooted in the meticulous development of performance indicators based on the questionnaire methodology. This tool provides a robust foundation for data analysis and enables the evaluation of wineries' effectiveness in managing Critical Control Points (CCPs) associated with contamination risks posed by arsenic, cadmium, and lead in grapes and wines.

5. Conclusions

This research shows that although most wineries have FSMS implemented, the CCP identification and control related to arsenic, cadmium and lead contamination risk needs to be improved.

Wineries must adequately control the risk of arsenic, cadmium, and lead contamination in the wine production process. To do it, first, wineries must be aware of the need to know, update and implement European legislation. European legislation sets the guidelines to prevent health risks that may arise from the intake of arsenic, cadmium, or lead by setting limits on the admissible concentration of these metals in wines. In addition, wineries′ workers′ training in GMP and CCPs control is a success factor in preventing contamination by arsenic, cadmium, and lead in wines.

A strength in the performance of CCP control aimed at assessing the risk of arsenic, cadmium and lead contamination is high training level of workers about this topic. However, the wineries performance about applicable legislation identification of the heavy metal contamination risk is very low. This constitutes a difficulty for good performance of CCP controlling relative to the risk of contamination by arsenic, cadmium, and lead. In addition, another difficulty for this performance is the lack of information regarding the sources of contamination by arsenic, cadmium, and lead in grapes. Soil analysis data about pH and EC are available to wineries, but data about the concentrations of As, Cd and Pb in the soil are often missing.

Another barrier to a good performance of the CCP related to contamination of grapes by arsenic, cadmium, and lead is the lack of spectrometry equipment in the laboratories of the wineries. Even if external services are hired for spectrometric analysis, the percentage of wineries that perform it is very low. Providing wineries with laboratory spectrometry equipment and human resources to carry out complete chemical analyses of soils, grapes and wines would allow the adequate control of CCP related to contamination risk control by heavy metals and metalloids of their grapes and wines.

Ethic statement

The authors confirm that the study and data collection comply with all ethics regulations and confirm that informed consent was obtained from the participants in collecting data.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Data availability statement

Data associated with the study has not been deposited into a publicly available repository and data will be made available on request.

CRediT authorship contribution statement

Jesús López-Santiago: Writing - review & editing, Writing - original draft, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Ana Isabel García García:** Supervision. **Alejandro Gómez Villarino:** Validation, Methodology. **Amelia Md Som:** Writing - review & editing, Validation, Supervision, Methodology. **María Teresa Gómez-Villarino:** Writing - review & editing, Validation, Supervision, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Analysis of wineries performance about Critical Control Point related to risk control contamination by arsenic, cadmium, and lead in grapes/wines during winemaking.

* Obligatory.

General data of the winery

G.1 What is your annual level of red wine production? * (Mark only one).
up to 25,000 liters/year
between 25,001 and 100,000 liters/year
between 100,001 and 250,000 liters/year
between 250,001 and 500,000 liters/year more than 500,001 liters/year.
G.2 Do you have a prerequisite program in place, according to the legislation on food hygiene? * (Mark only one).
Yes/No.
G.3 Does the winery have a Critical Point Analysis System in place and Control (HACCP)? * (Mark only one).
Yes/No.
G.4 How many people work in wine production operations in the winery? *
G.5 Do winery workers have training about good manufacturing practices (GMP)? * (Mark only one).
No worker has GMP training.
More than half of workers have GMP training.
All workers have GMP training.
G.6 Do winery workers have control training and monitoring of critical control points (CCPs)? * (Mark only one).
No worker has training in control and monitoring of CCPs.
More than half of workers have training in control and monitoring of the CCPs.
All workers have training in control and monitoring of the CCPs.

Information available on arsenic, cadmium and leads in the raw material (Critical Control Point)

ID 1. The winery has identified the legislation relating to food contamination by: (check all those you consider).
Arsenic/Cadmium/Lead.
ID 2. The winery uses the updated information available from the Spanish Agency for Food Safety and Nutrition (AESAN) on heavy metals food risk. * (Mark only one).
Yes/No.
CS 1. Does the winery have information related to physic-chemical analysis of where do the grapes used in winemaking come from? * (Mark only one).
Yes (Skip to question 11)/No.
CS 2. Does the winery have information on the fertilizers used in the fertilization of the soil from which the grapes used in winemaking come from? * (Mark only one).
Yes/No.

Information available of the concentration of arsenic, cadmium, and lead in the soil

CS 3. The available information on the analysis of vineyard arable soil holds data on:
Select all that apply.
Total Arsenic Concentration in Soil.
Concentration of Arsenic Available in Soil.
Total Cadmium Concentration in Soil.
Cadmium Concentration Available in Soil.
Total Lead Concentration in Soil.
Lead Concentration Available in Soil.
Soil pH.
Electrical conductivity of the soil.

Control of the raw material (analysis procedures in the winery)

CB 1. Does the winery have its own laboratory to perform chemical analysis of grapes and wines? * (Mark only one).
Yes/No.
CB 2. If you do NOT have your own laboratory, do you use an external laboratory to perform chemical analysis of grapes and wines? * (Mark only one).
Yes/No.
CB 3. Does the warehouse have the technology and personnel to perform metal analysis using atomic absorption spectrometry? * (Mark only one).
Yes/No.
CB 4. If you do NOT have your own laboratory, do you use an external laboratory to perform metal analysis using atomic absorption spectrometry on grapes and wines? *
Yes/No.

Professional profile that performs the survey

You can tell us about your job inside the winery. (Mark only one).
Owner.
Director/Manager.
Winemaker
Winery Operator.
Administrative/management/commercial staff.
Other.

References

[1] J.C. Lee, A. Daraba, C. Voidarou, G. Rozos, H.A. El Enshasy, T. Varzakas, Implementation of food safety management systems along with other management tools (HAZOP, FMEA, Ishikawa, Pareto). The case study of Listeria monocytogenes and correlation with microbiological criteria, Foods 10 (2021) 2169.
[2] S. Galani-Nikolakaki, N. Kallithrakas-Kontos, A.A. Katsanos, Trace element analysis of Cretan wines and wine products, Sci. Total Environ. 285 (2002) 155.
[3] D. Vitali Čepo, M. Pelajić, I. Vinković Vrček, A. Krivohlavek, I. Žuntar, M. Karoglan, Differences in the levels of pesticides, metals, sulphites and ochratoxin A between organically and conventionally produced wines, Food Chem. 246 (2018) 394–403.
[4] H. Eschnauer, R. Neeb, Micro-element Analysis in Wine and Grapes, Wine analysis, 1988, pp. 67–91.
[5] A. Garcia-Sanchez, E. Alvarez-Ayuso, Arsenic in soils and waters and its relation to geology and mining activities (Salamanca Province, Spain), J. Geochem. Explor. 80 (2003) 69–79.
[6] S. García-Salgado, D. García-Casillas, M.A. Quijano-Nieto, M.M. Bonilla-Simón, Arsenic and heavy metal uptake and accumulation in native plant species from soils polluted by mining activities, Water, Air, Soil Pollut. 223 (2012) 559–572.
[7] M. Díez, M. Simón, C. Dorronsoro, I. García, F. Martín, Background arsenic concentrations in Southeastern Spanish soils, Sci. Total Environ. 378 (2007) 5–12.
[8] R. Jiménez-Ballesta, S. Bravo, C. Pérez-de-los-Reyes, J.A. Amorós, F.J. García-Navarro, Contents and Spatial distribution of arsenic in vineyard soils in mediterranean environment. Water, air, & Soil Pollution 234 (2023) 83.
[9] A. Andersson, K.O. Nilsson, Enrichment of trace elements from sewage sludge fertilizer in soils and plants, Ambio (1972) 176–179.
[10] T. Milićević, M. Aničić Urošević, D. Relić, G. Jovanović, D. Nikolić, K. Vergel, A. Popović, Environmental pollution influence to soil–plant–air system in organic vineyard: bioavailability, environmental, and health risk assessment, Environ. Sci. Pollut. Res. 28 (2020) 3361–3374.
[11] Codex Alimentarius Commission Codex Alimentarius, General Principles of Food Hygiene. CXC 1-1969, 2011.
[12] World Health Organization, Guidance on regulatory assessment of HACCP: report of a joint FAO/WHO consultation on the role of government agencies in assessing HACCP, Geneva, 2-6 June 1998, in: Guidance on Regulatory Assessment of HACCP: Report of a Joint FAO/WHO Consultation on the Role of Government Agencies in Assessing HACCP, Geneva, 1998.
[13] H.E. Bauman, In the origin and concept of HACCP; HACCP in meat, poultry, and fish processing, Springer (1995) 1–7.
[14] A.A. Ali, R.M. Fischer, Implementation of HACCP to bulk cream and butter production line, Food Rev. Int. 21 (2005) 189–210.
[15] European Commission.Commission Notice (2022/C 355/01) on the implementation of food safety management systems covering Good Hygiene Practices and procedures based on the HACCP principles, including the facilitation/flexibility of the implementation in certain food businesses (2022) 1–58, 2022/C 355/01.
[16] European Commission, Commission Notice on the implementation of food safety management systems covering prerequisite Programmes (PRPs) and procedures based on the HACCP principles, including the facilitation/flexibility of the implementation in certain food businesses, OJ C 2016 278 (2016) 1–32.
[17] S. Mortimore, C. Wallace, HACCP: A Practical Approach, Springer Science & Business Media, 2013.
[18] E. Walker, C. Pritchard, S. Forsythe, Hazard analysis critical control point and prerequisite programme implementation in small and medium size food businesses, Food Control 14 (2003) 169–174.
[19] W.H. Sperber, in: M.D. Pierson, D.A. Corlett (Eds.), In Determining Critical Control Points, HACCP: Principles and Applications, Springer US, Boston, 1992, pp. 39–49.
[20] International Organisation of Vine and Wine Resolution OIV-OENO 630-2020. OIV Guide to Identify Hazards, Critical Control Points and Their Management in the Wine Industry, OIV Standards and Technical documents, Paris, 2020.
[21] H. Chen, S. Liu, Y. Chen, C. Chen, H. Yang, Y. Chen, Food safety management systems based on ISO 22000: 2018 methodology of hazard analysis compared to ISO 22000: 2005, Accred Qual. Assur. 25 (2020) 23–37.
[22] T. Christaki, C. Tzia, Quality and safety assurance in winemaking, Food Control 13 (2002) 503–517.
[23] S. Benito, The management of compounds that influence human health in modern winemaking from an HACCP point of view, Fermentation 5 (2019) 33.
[24] A.J. Martínez-Rodríguez, A.V. Carrascosa, HACCP to control microbial safety hazards during winemaking: ochratoxin A, Food Control 20 (2009) 469–475.
[25] N. Magan, Mycotoxin contamination of food in Europe: early detection and prevention strategies, Mycopathologia 162 (2006) 245–253.
[26] V. Bermúdez Leirós, Diseño y dimensionamiento de una bodega de vino tinto D.O. La Mancha de 300.000 Kg de uva de capacidad en Pozoamargo (Cuenca), 2020.
[27] J. López-Santiago, A.I.G. García, M.T. Gómez-Villarino, An evaluation of food safety performance in wineries, Foods 11 (9) (2022) 1249.

[28] C. Herce-Pagliai, I. Moreno, G. González, M. Repetto, A.M. Cameán, Determination of total arsenic, inorganic and organic arsenic species in wine, Food Addit. Contam. 19 (6) (1992) 542–546.
[29] OIV Collective Expertise Lead in Wine: A Review, OIV publications, 2020. https://www.oiv.int/public/medias/7336/oiv-collective-expertise-lead-in-wine-a-review.pdf. (Accessed 6 October 2023).
[30] European Commission, Commission Regulation (EU) 2021/1323 of 10 August 2021 amending Regulation (EC) No 1881/2006 as regards maximum levels of cadmium in certain food stuffs, Off. J. Eur. Union L 288 (2021) 13–18.
[31] European Commission, Commission Regulation (EC), No 1881/2006 maximum levels for certain contaminants in foodstuffs (Text with EEA relevance), Off. J. Eur. Union L 364 (2006) 5–23.
[32] European Commission, Commission Regulation (EC), No 333/2007 of 28 March 2007 laying down the methods of sampling and analysis for the official control of the levels of lead, cadmium, mercury, inorganic tin, 3-MCPD and benzo(a)pyrene in foodstuffs (Text with EEA relevance), Off. J. Eur. Union L 88 (2007) 29–38.
[33] European Commission, Commission Recommendation of 4 April 2014 on the reduction of the presence of cadmium in foodstuffs (Text with EEA relevance), Off. J. Eur. Union L 104 (2014) 80–81.
[34] European commission, commission recommendation (EU) 2015/1381 of 10 august 2015 on the monitoring of arsenic in food, Off. J. Eur. Union L 213 (2015) 9–10.
[35] Organisation Internationale de la Vigne et du Vin, International Enological Codex, Organisation Internationale de la Vigne et du Vin, Paris, 2022. https://www.oiv.int/standards/international-code-of-oenological-practices/annexes/maximum-acceptable-limits. (Accessed 1 October 2023).
[36] Slavica Ražić, Marija Todorović, Ivanka Holclajtner-Antunović, Milovan Stoiljković, Determination of metal traces in wine by argon stabilized d.c. arc, Fresenius' J. Anal. Chem. 365 (1999) 367–370.
[37] N. M Mañay, G. Clavijo, L. Díaz, Absorción atómica con horno de grafito, Repositorio de la Facultad de Química de la Universidad de la República, Monografía 2 (2009) 5 79–92. http://riquim.fq.edu.uy/archive/files/02ba23e6cc083af03bfc55ac63a98a0c.pdf. (Accessed 1 October 2023).
[38] International Organisation of Vine and Wine OIV-MA-AS323-01A Determination of arsenic in wine by atomic absorption spectrometer. https://www.oiv.int/standards/annex-a-methods-of-analysis-of-wines-and-musts/section-3-chemical-analysis/section-3-2-non-organic-compounds/section-3-2-3-other-non-organic-compounds/arsenic-%28aas%29-%28type-iv%29 (accessed 13/June/2023).
[39] International Organisation of Vine and Wine OIV-MA-AS322-10 Cadmium. https://www.oiv.int/standards/annex-a-methods-of-analysis-of-wines-and-musts/section-3-chemical-analysis/section-3-2-non-organic-compounds/section-3-2-2-cations/cadmium-%28type-iv%29, 2023. (Accessed 13 June 2023).
[40] International Organisation of Vine and Wine Heavy metals by ETAAS (Type-IV) OIV-MA-F1-10 Specific methods. https://www.oiv.int/standards/compendium-of-international-methods-of-wine-and-must-analysis/annex-f/annex-f-specific-methods-for-the-analysis-of-grape-sugar/heavy-metals-by-etaas-%28type-iv%29 (accessed 13/June/2023).
[41] Federación Española del Vino El sector vitivinícola en cifras. http://www.fev.es/sector-cifras/, 2022. (Accessed 28 November 2022).
[42] Ministerio de Agricultura, Pesca y Alimentación. Gobierno de España. Wines Protected Designation of Origin List. https://www.mapa.gob.es/es/alimentacion/temas/calidad-diferenciada/dop-igp/Default.aspx (accessed 28/November/2022).
[43] N. Asiamah, H.K. Mensah, E. Oteng-Abayie, Non-probabilistic sampling in quantitative clinical research: a typology and highlights for Students and early career researchers, International Journal of Applied Research on Public Health Management 7 (2022) 1–18.
[44] H.Ö. Ayhan, In Non-probability Sampling Survey Methods, International Encyclopedia of Statistical Science, Springer Berlin Heidelberg, 2014, pp. 979–982.
[45] E. Abascal, I.G. Esteban, Análisis de encuestas, Libros profesionales de empresa, ESIC Editorial, Madrid (España), 2005, pp. 50–62.
[46] P.J. Panisello, P.C. Quantick, Technical barriers to hazard analysis critical control point (HACCP), Food Control 12 (2001) 165–173.
[47] G.S.R. Krishnamurti, R. Naidu, Solid–solution equilibria of cadmium in soils, Geoderma 113 (2003) 17.
[48] E. Abascal, Grande I., Análisis de encuestas; Libros profesionales de empresa, ESIC Editorial, Madrid (España), 2005, pp. 26–29.
[49] J.C. Lee, M. Neonaki, A. Alexopoulos, T. Varzakas, Case studies of small-medium food enterprises around the world: major constraints and benefits from the implementation of food safety management systems, Foods 12 (2023) 3218.
[50] V. Cloquell-Ballester, R. Monterde-Díaz, V. Cloquell-Ballester, A.d.C. Torres-Sibille, Environmental education for small- and medium-sized enterprises: methodology and e-learning experience in the Valencian region, J. Environ. Manag. 87 (2008) 507–520.
[51] L.M. Campos, D.A. de Melo Heizen, M.A. Verdinelli, P.A. Cauchick Miguel, Environmental performance indicators: a study on ISO 14001 certified companies, J. Clean. Prod. 99 (2015) 286–296.
[52] Agencia Española de Seguridad Alimentaria y Nutrición, (AESAN), Sobre AESAN (2022), https://www.aesan.gob.es/AECOSAN/web/agencia/seccion/sobre_aesan.htm.(accessed 04/12/2022)..
[53] Agencia Española de Seguridad Alimentaria y Nutrición Metales y otros contaminantes medioambientales e industriales (2022), https://www.aesan.gob.es/AECOSAN/web/seguridad_alimentaria/ampliacion/metales_pesados.htm.(accessed 04/12/2022)..
[54] C. Chen, H. Chiou, W. Huan, S. Chen, Y. Hsueh, C. Tseng, L. Lin, M. Shyu, M. Lai, in: C.O. Abernathy, R.L. Calderon, W.R. Chappell (Eds.), In Systemic Non-carcinogenic Effects and Developmental Toxicity of Inorganic Arsenic, Arsenic: Exposure and Health Effects, Springer Netherlands, Dordrecht, 1997, pp. 124–134.
[55] S.J.S. Flora, G. Flora, G. Saxena, in: J.S. Casas, J. Sordo (Eds.), In Chapter 4 - Environmental Occurrence, Health Effects and Management of Lead Poisoning, Lead, Elsevier Science B.V., Amsterdam, 2006, pp. 158–228.
[56] A.R. Vela, J.M. Fernández, Barriers for the developing and implementation of HACCP plans: results from a Spanish regional survey, Food Control 14 (2003) 333–337.
[57] L.K. Kourtis, I.S. Arvanitoyannis, Implementation of hazard analysis critical control point (HACCP) system to the alcoholic beverages industry, Food Rev. Int. 17 (2001) 1–44.
[58] C. Yapp, R. Fairman, Factors affecting food safety compliance within small and medium-sized enterprises: implications for regulatory and enforcement strategies, Food Control 17 (2006) 42–51.
[59] M. Allam, R. Bazok, U. Bordewick-Dell, E. Czarniecka-Skubina, R. Kazimierczak, K. Laikoja, A. Luik, M.M. Fuka, R. Muleo, E. Peetsmann, Assistance needed for increasing knowledge of HACCP food safety principles for organic sector in selected EU countries, Sustainability 15 (2023) 6605.
[60] L. Yang, Q. Ren, K. Zheng, Z. Jiao, X. Ruan, Y. Wang, Migration of heavy metals in the soil-grape system and potential health risk assessment, Sci. Total Environ. 806 (2022), 150646.
[61] M. Xiang, Y. Li, J. Yang, K. Lei, Y. Li, F. Li, D. Zheng, X. Fang, Y. Cao, Heavy metal contamination risk assessment and correlation analysis of heavy metal contents in soil and crops, Environ. Pollut. 278 (2021), 116911.
[62] C.K. Tanabe, J. Nelson, S.E. Ebeler, Current perspective on arsenic in wines: analysis, speciation, and changes in composition during production, J. Agric. Food Chem. 67 (2019) 4154–4159.

4.3 Conference Paper

López-Santiago, J., Gómez-Villarino, M. T., García, A. I. G.., A. M., Som, (2023). **An Evaluation of Sustainability in Wineries Based on Their Performance in Compliance with Food Safety.** In Proceedings of the 12th Iberian Agroengineering Congress. XII Congreso Ibérico de Agroingeniería. (2023) Junta de Andalucía: Sevilla - Spain. ISBN: 978-84-09-53018-2

This paper addresses the **specific objective 3 (SO-3)**, which focuses on identifying and analysing key sustainability components in wineries. It evaluates their compliance with FS standards, especially via the CCPs within the HACCP framework. It highlights the wineries challenge of adopting sustainable production methods while addressing environmental impacts and enhancing working conditions. The paper synthetizes the case studies one and two approach to scrutinize wineries management of CCPs, focusing on the risk of contamination by trace metals such as arsenic, cadmium, and lead in wine production. The findings reveal that many wineries lack adequate control over several CCPs, with significant deficiencies in managing chemical hazards related to trace metals in grapes and wine, as well as biological hazards on equipment and during operational stages.

The second study also delves into the specific issue of contamination risk by arsenic, cadmium, and lead, showing that wineries fall short in areas of analysis and compliance with relevant legislation. It proposes using performance indicators related to training, legal compliance, and physical-chemical analysis to gauge progress in implementing effective food safety systems within wineries.

Moreover, the research underscores the necessity for continuous improvement in the technical application of HACCP and in training winery staff on food safety. It suggests that enhancing CCP surveillance and the overall execution of HACCP can significantly contribute to mitigating food safety risks and, consequently, fostering sustainability based on FS measures. The study concludes that controlling the risk of contamination by arsenic, cadmium, and lead is crucial, necessitating up-to-date knowledge and implementation of European legislation, along with comprehensive training in GMP and CCP control to prevent such contamination in wines.

The findings address the question of how we can obtain a quantitative measure of sustainability in wine production from the perspective of FS by proposing the methodology and performance indicators.

An evaluation of sustainability in wineries based on their performance in compliance with food safety.

Jesús López-Santiago[1]*, María Teresa Gómez-Villarino[1], Ana Isabel García García[1] and Amelia Md Som[2]

[1] Agroforestry Engineering Department, School of Agricultural, Food and Biosystems Engineering, Universidad Politécnica de Madrid, 28040 Madrid, Spain; jesus.lopez.santiago@upm.es; ai.garcia@upm.es; teresa.gomez.villarino@upm.es

[2] Green Chemistry & Sustainable Technology Cluster, Universiti Kuala Lumpur, Malaysian Institute Chemical & Bioengineering Technology, Alor Gajah, 78000, Malacca, Malaysia; ameliamds@unikl.edu.my

*** Correspondence: jesus.lopez.santiago@upm.es; Tel.: +34-913-365-837**

Abstract:

Agri-food industry is confronted with a significant challenge concerning the requirement for sustainable food production methodologies. Companies within the agrifood sector encounter both challenges and prospects, such as the integration of responsible agricultural practices, mitigation of environmental impact, and enhancement of working conditions. This research pertains to the employment of metrics as a means of assessing sustainable practices, specifically in reference to food safety performance indicators. Wine production is employed as a dual case study to assess the efficacy of wineries in managing critical control points (CCPs). The first aspect focuses on CCP system, as a component of a food safety system based on pre-requisite programs (PPRs) and hazard analysis and critical control points (HACCP). The second aspect specifically addresses the performance in the risk of contamination by arsenic, cadmium, and lead CCP during wine production. The first study showed that wineries have poor control performance for 15 out of the 37 CCPs evaluated, and the worst control performance seems to be related to chemical controls of trace metals, fungicides, and pesticides in grapes or wine, biological controls of microorganisms on equipment, and controls in the operational stage. The second investigation analyzed the performance of wineries in controlling the CCP related to the risk of contamination by arsenic, cadmium, and lead during wine production. The results showed that wineries are failing in the areas of analysis and legislation. Using performance indicators of training, legislation, and physical-chemical analysis can serve as a qualitative measure of progress in implementing food safety systems in wineries.

Palabras clave: beverages; HACCP; food safety; wine; sustainable production

---

1. Introduction

Currently, it is observed that agricultural and food production is not being carried out sustainably [1]. According to the European Commission, food production continues to have a negative impact on the environment of the European Union (EU), while 20% of produced food is wasted. Although agriculture in the EU has made significant progress in reducing greenhouse gas emissions and nitrate levels in rivers since 1990, there is still much to be done throughout the entire food chain [2]. Therefore, it is necessary to propose a new framework for food production and processing at the industrial level, in line with sustainability principles.

It is essential to develop food production methods that are compatible with the conservation of the environment. In other words, it is imperative to implement agro-industrial production methods that minimize the impact on ecosystems and natural resources, while ensuring food safety and healthy nutrition for consumers [3].

Sustainability in the agri-food industry is still in its early stages. Numerous studies have provided perspectives on the challenges and opportunities faced by companies in the agri-food sector. However, due to the growing complexity of this field, it is necessary to develop more systematic approaches that include sustainability [4]. It is imperative to implement responsible agricultural practices, reduce environmental impact, and improve working conditions. These measures can contribute to the conservation of natural resources, improve the quality of the final product, and promote the economic development of local communities.

Often, the approaches used in the agri-food industry do not simultaneously achieve these objectives, which can generate negative effects such as lack of food safety or serious environmental impacts. Food or ecosystem contamination, food poisoning derived from deficient agro-industrial practices, the use of chemicals in agro-industrial production processes, are some examples of this reality.

Gold et al. [5] specified the dimension of sustainability through indicators such as local living conditions, labor rights, land rights, food security, valorization through biomass recycling, and environmental issues. In this context, food security is a useful indicator within the sustainability dimension to analyze the sustainability performance of the agri-food supply chain.

Wine production is an integral part of the food chain and is closely related to the sustainability of the food chain. Wine production involves the cultivation of grapes, the transformation of grapes into wine, and the distribution and commercialization of the final product [6]. It is a fact that wine production presents risks to food safety. Wineries have implemented food safety management systems to control food risks through Hazard Analysis and Critical Control Points (HACCP). The wine industry applies HACCP by evaluating Critical Control Points (CCP). A Hazard Analysis and Critical Control Points (HACCP) system allows identifying, assessing, and controlling significant food safety risks throughout the entire wine production process.

2. Materials and methods

A first investigation analyzed the Prerequisite Programs (PPRs) and the performance of HACCP in the wineries with Protected Designation of Origin "Vinos de Madrid". The performance of wineries was evaluated for each critical control point (CCP) at each stage of the wine production process, including the implementation of PPR and HACCP principles. This study was carried out through a survey of 55 questions divided into 11 sections and was conducted on a sample of 21 wineries.

A second investigation selected one of the CCPs identified as poorly controlled. This CCP is the risk of contamination by arsenic, cadmium, and lead during wine production. The level of performance of wineries in controlling CCPs related to the risk of contamination by arsenic, cadmium, and lead in wine production was analyzed through a sixteen-question questionnaire that was administered to a sample of 32 wineries from all the Protected Designations of Origin in Spain. Subsequently, three indicators were calculated for the performance components of training, legislation, and analysis in controlling this CCP.

3. Results and discussion

The results of the first investigation determined that performance control for each of the 37 evaluated CCPs during wine production is different (see **Table 1**). A total of 22 CCPs are well-evaluated by wineries. However, there are significant differences among the other 15 CCPs depending on each winery. The worst control performance among wineries for CCPs seems to be related to chemical controls of trace metals, fungicides, and pesticides in grapes or wine, biological controls of microorganisms on equipment, and controls in the operational stage such as remaining time of must in crushers [7].

Table 1. Contingency table of the medians of each variable associated to each evaluated CCP.

	Frequencies	Always (3)	Usually (2)	Hardly Ever (1)	Never (0)	High Variability
Winemaking Steps	**Variable/Critical Control Point (CCP)**					
1. Harvest and grape transportation	VAR1.1 Grape inspection previous harvest in vineyards.					Y
	VAR1.2 Grape inspection during harvest in vineyards.					
	VAR1.3 Transportation time of harvest from vineyards to winery.					Y
2. Harvest reception in the winery	VAR2.1 Presence of fungicide residues and/or pesticides in grapes.					Y
	VAR2.2 Presence of mycotoxins from grape rot.					
	VAR2.3 Contamination by metals (Cadmium, Lead, Arsenic) in grapes.					Y
	VAR2.4 Contamination by plant residues, dust and/or metal elements.					
3. Pre-hatching treatments	VAR3.1 Vat cleaning to eliminate residues of microorganisms.					
	VAR3.2 No residues of cleaning and disinfection products in vats.					
4. Grapes crushing and must pumping	VAR4.1 Time that remains the must in the crusher after crushing.					Y
	VAR4.2 Cleaning of crushing equipment.					
	VAR4.3 No residues of cleaning and disinfection products in vats.					
5. Sulphited and vatted	VAR5.1 Safety and purity of the additives.					Y
	VAR5.2 No microorganisms in equipment and vats.					
6. Alcoholic fermentation, maceration, vat emptying, pressing, malolactic fermentation	VAR6.1 Concentration of ethylocarbamate in fermented must.					Y
	VAR6.2 Concentration of sulphur dioxide in fermented must.					
	VAR6.3 Purity and safety of yeasts.					Y
	VAR6.4 Temperature during fermentation.					
	VAR6.5 pH of red wine during malolactic fermentation.					
	VAR6.6 Hygiene during vat emptying/pressing operations.					
	VAR6.7 Cleaning of pressing equipment.					Y
7.Racking, clarification, and filtration	VAR7.1 Cleaning procedures for vats and racking equipment.					
	VAR7.2 Maintenance and cleaning of the facilities during racking.					
	VAR7.3 Purity and safety of agents used as clarifiers of the wine.					Y
	VAR7.4 No residues of clarifiers in the wine.					Y
	VAR7.5 No weird elements from filters in the wine.					
	VAR7.6 Hygiene during clarification and filtering operations.					
	VAR7.7 No residues of cleaning and disinfection products in vats.					
8. Cold stabilization	VAR8.1 Limit concentrations of metals (traces of As, Cu, Pb) in the wine.					Y
	VAR8.2 Additives accepted by current food legislation.					
9. Bottling and labelling	VAR9.1 Bottle cleaning procedures.					Y
	VAR9.2 Cleaning procedures of the bottling line.					
	VAR9.3 No microorganisms in the bottling line.					Y
	VAR9.4 No microorganisms in bottle cap.					Y
	VAR9.5 Correct coding of the label used on the bottles.					
	VAR9.6 Correct description of allergen information on bottle labels.					
	VAR9.7 Correct description of P.D.O. information on bottle labels.					

Poorly controlled CCPs assume that hazards such as the appearance of microorganisms, trace metals, fungicides, pesticides, or other hazardous products in grapes or wine can occur [8-10].

The second research showed that wineries are failing in the areas of analysis and legislation of the risk of contamination by arsenic, cadmium, and lead CCP during wine production. The identification and updating of legislation regarding the risk of contamination by As, Cd, and Pb is at an initial performance level for wineries that produce less than 250,000 L/year. The performance level of analysis is even lower than that of legislation. One in three wineries has information on the concentrations of arsenic, cadmium, and lead in the soils of the vineyards where the grapes come from, and this rate is even lower for their concentration available in the soil solution. Wineries that monitor the concentrations of As, Cd, and Pb do so according to official recommendations using techniques based on atomic absorption spectrometry. However, there is a lack of spectrometry equipment in the winery laboratories themselves.

The second research allowed the design of three performance indicators based on the responses obtained from wineries [11, 12]. Wineries were distributed in five groups according to their yearly wine production to calculate them. Performance indicators allow to determine the degree of progress wineries had reached related to the control they conduct on the contamination risk of arsenic, cadmium, and lead in grapes and wines. Components performance level by each winery sizes production level on the contamination risk by arsenic, cadmium, and lead in wines are showed in **Table 2**.

Table 2. Wineries performance indicators and grade of progress, by type of winery.

Wineries size	I_{fswt}	Grade of progress	I_{liu}	Grade of progress	$I_{ccp-Mchem}$	Grade of progress
Up to 25,000 L/year	0,89	Maturity	0,44	In progress	0,05	Start
25,001-100,000 L/year	0,77	Maturity	0,15	Start	0,08	Start
100,001-250,000 L/year	0,78	Maturity	0,28	Start	0,51	In progress
250,001-1,000,000 L/year	0,94	Maturity	0,66	In progress	0,56	In progress
More than 500,000 L/year	0,93	Maturity	0,60	In progress	0,42	In progress

4. Conclusions

This work demonstrates the need to continue improving in the technical implementation of the HACCP methodology and in training workers about food safety in wineries. Establishment of new CCPs surveillance formats involving the different professionals working in the wineries (enologist, manager, winery operators, quality managers) will improve performance in the CCPs surveillance, and by extension, the deployment level of the entire HACCP. A good implementation of PPR and HACCP contributes to eliminating food safety risks that compromise people's health, being the basis for the development of sustainability based on the food safety indicator.

Also, wineries must adequately control the risk of arsenic, cadmium, and lead contamination in the wine production process. To do it, first, wineries must be aware of the need to know, update and implement European legislation. European legislation sets the guidelines to prevent health risks that may arise from the intake of arsenic, cadmium, or lead by setting limits on the admissible concentration of these metals in wines. In addition, wineries´

workers´ training in GMP and CCPs control is a success factor in preventing contamination by arsenic, cadmium, and lead in wines.

Moreover, the performance indicators of training, legislation, and physical-chemical analysis performance, developed through the analysis of the implementation of the CCP, serve as a qualitative measure of the progress in the three performance dimensions related to the implementation of food safety systems. This approach can be extended to all CCP system in wine production, thus becoming a qualitative method for evaluating the sustainability of wineries.

References

1. McGreevy, S. R.; Rupprecht, C. D. D.; Niles, D.; Wiek, A.; Carolan, M.; Kallis, G.; Kantamaturapoj, K.; Mangnus, A.; Jehlička, P.; Taherzadeh, O.; Sahakian, M.; Chabay, I.; Colby, A.; Vivero-Pol, J.; Chaudhuri, R.; Spiegelberg, M.; Kobayashi, M.; Balázs, B.; Tsuchiya, K.; Nicholls, C.; Tanaka, K.; Vervoort, J.; Akitsu, M.; Mallee, H.; Ota, K.; Shinkai, R.; Khadse, A.; Tamura, N.; Abe, K.; Altieri, M.; Sato, Y.; Tachikawa, M. Sustainable agrifood systems for a post-growth world. *Nature sustainability* **2022**.

2. European Commission Documento de Reflexión hacia una Europa Sostenible en 2030. **2019**.

3. Dobermann, D.; Swift, J. A.; Field, L. M. Opportunities and hurdles of edible insects for food and feed. *Nutr Bull* **2013**, *42*, 293.

4. Barth, H.; Ulvenblad, P.; Ulvenblad, P. Towards a conceptual framework of sustainable business model innovation in the agri-food sector: a systematic literature review. *Sustainability* **2017**, *9*, 1620.

5. Gold, S.; Kunz, N.; Reiner, G. Sustainable Global Agrifood Supply Chains: Exploring the Barriers. *Journal of industrial ecology* **2017**, *21*, 249-260.

6. Robertson, G. L. *Food packaging: principles and practice. Chapter 20.* ; CRC press: Boca Raton (USA), 2006; .

7. López-Santiago, J.; García, A. I. G.; Gómez-Villarino, M. T. An Evaluation of Food Safety Performance in Wineries. *Foods* **2022**, *11*.

8. Christaki, T.; Tzia, C. Quality and safety assurance in winemaking. *Food Control* **2002**, *13*, 503-517.

9. Martinez-Rodriguez, A. J.; Carrascosa, A. V. HACCP to control microbial safety hazards during winemaking: Ochratoxin A. *Food Control* **2009**, *20*, 469-475.

10. Magan, N. Mycotoxin contamination of food in Europe: Early detection and prevention strategies. *Mycopathologia* **2006**, *162*, 245-253.

11. Cloquell-Ballester, V.; Monterde-Díaz, R.; Cloquell-Ballester, V.; Torres-Sibille, A. d. C. Environmental education for small- and medium-sized enterprises: Methodology and e-learning experience in the Valencian region. *Journal of environmental management* **2008**, *87*, 507-520.

12. Campos, L. M. S.; de Melo Heizen, Daiane Aparecida; Verdinelli, M. A.; Cauchick Miguel, P. A. Environmental performance indicators: a study on ISO 14001 certified companies. *Journal of cleaner production* **2015**, *99*, 286-296.

4.4 Article three

López-Santiago, J., García, A. I. G., Villarino, A. G., Som, A. M., & Gómez-Villarino, M. T. (2024). **Assessment of Environmental Management Performance in Wineries: A Survey-Based Analysis to create Key Performance Indicators. Environments** 2024, UNDER PEER REVIEW (18-04-2024)

The investigation addresses the **specific objective 2 (SO-2) and the specific objective 3 (SO-3)**, which involves evaluating environmentally sustainable practices in the wine industry by examining the extent of EMS implementation in accordance with the international standard ISO 14001:2015, and its efficacy as an instrument for assessing sustainability within wineries.

Findings reveal a notable distribution disparity among wineries, with 75% producing less than one hundred thousand litres annually, while 12.5% exceed one million litres. This pattern underscores the duality of the Italian wine sector, characterized by a high number of small wineries with lower annual productions and a smaller number of large wineries with higher annual outputs.

Concerning workforce, most of wineries (80.8%) employ fewer than ten workers, while 19.2% have a workforce ranging from 10 to 49 employees. The key areas of EM that wineries claim to consider, including EM, leadership, planning of environmental objectives, and communication. Results highlight a lack of clearly defined EM areas in Italian wineries, with only large wineries (80%) having implemented structured focus on EM.

Results about environmental communication practices, both internal and external, revealing that email is the most widely used internal communication medium (74.2%), followed by websites (45.2%) and social media (35.5%). External communication is predominantly through social media (84.4%) and websites (81.3%). Clients and shops emerge as the primary stakeholders receiving environmental information from wineries, emphasizing the use of Information and Communication Technologies (ICT) for communication.

A huge portion of wineries (71.9%) has established environmental policies and senior management leadership, with owners playing a pivotal role (50%).

Results identify key environmental objectives, such as waste and electricity consumption reduction, and evaluates the alignment with long-term environmental policy commitments. The study also notes that 68.8% of wineries have certified their EMS according to the ISO 14001:2015 standard.

Research finds that 38.7% of wineries lack an EEP, and 31.3% are certified according to the ISO 14001:2005 standard. The study emphasizes the importance of these requirements for establishing a solid foundation for EM.

Environmental training for workers results reveals that 71% of wineries provide training in connection with their EMS.

Finally, five performance indicators assess the performance of wineries in communication, commitment, planning, other requirements, and workers' training. The results provide a comprehensive understanding of the state of EM practices in Italian wineries, shedding light on areas of strength and areas that may require improvement.

Findings contribute to the research inquiries related to the assessment of winery performance in the context of EMS implementation. The results demonstrate that the employed methodology can assess the performance of wineries in their EM. Factors such as proper performance in management components such as communication, commitment, planning, other requirements, and workers' training contribute to explaining adequate performance in the implementation of EMS in wineries. Moreover, it contributes significantly aid in addressing the RQs concerning the quantitative assessment of EMS, specifically ISO 14001:2015, within wineries. They also help determine the environmental performance indicators that function as benchmarks for evaluating the sustainability impact of EM practices in the wine industry, and how these benchmarks align with the objectives of the F2F Strategy.

environments

MDPI

Article

Assessment of Environmental Management Performance in Wineries: A Survey-Based Analysis to create Key Performance Indicators.

Firstname Lastname [1], Firstname Lastname [2] and Firstname Lastname [2,*]

[1] Affiliation 1; e-mail@e-mail.com
[2] Affiliation 2; e-mail@e-mail.com
* Correspondence: e-mail@e-mail.com; Tel.: (optional; include country code; if there are multiple corresponding authors, add author initials)

Abstract: In the contemporary era, the viticulture sector is increasingly aligning with global sustainability mandates, underscored by the European Union's strategic integration of environmental sustainability within its regulatory and policy frameworks, notably through the Multiannual Environment Action Program and the European Green Deal. This research offers a comprehensive evaluation of the adoption and efficacy of Environmental Management Systems (EMS), specifically ISO 14001:2015, within Italian wineries, aiming to discern the extent of their commitment, planning, communication, emergency preparedness, and employee training towards environmental management. Employing a survey-based analytical approach complemented by statistical analysis through SPSS and Excel, this research identifies key challenges and opportunities that hinge on the wineries operational scale, varying degrees of engagement, and the effectiveness of communication strategies. It emerges that while there exists a substantial commitment towards environ-mental objectives—primarily waste reduction, and efficient electricity and water use—a significant proportion of wineries exhibit gaps in EMS policy implementation, emergency preparedness, and ISO 14001:2015 certification uptake. Furthermore, the research highlights a disparity in environmental training, with larger wineries showing higher engagement levels. Despite potential biases arising from participation rates, the robustness of survey-based key performance indicators substantiates their utility in assessing wineries EMS performance.

Keywords: environmental management, environmental methodologies, key performance indicators, sustainable wineries, clean production

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Received: date
Revised: date
Accepted: date
Published: date

1. Introduction

Over the past two decades, the European Union (EU) has increasingly prioritized environmental sustainability and commitment to the environment. In 2001, the EU integrated environmental issues into the Lisbon Strategy with the first European sustainable development strategy [1]. Subsequently, in 2016, the EU incorporated the Sustainable Development Goals of the United Nations Agenda 2030 [2] through the communication titled "Next steps for a sustainable European future - European action for sustainability" [3]. To ensure effective implementation of environmental legislation in all member states, the European Commission established an instrument in May 2016 [4]. In 2020, the EU strengthened its environmental commitment further with the 8th Multiannual Environment Action Programme from 2021 to 2030, which aims to "ensure well-being for all while respecting the limits of the planet" [5]. Additionally, the environmental and climate objectives of the European Green Deal are supported by the 8th Multiannual Environmental Action Programme [6].

Environmental management (EM) is based on a multi-level cyclical process in which different environmental managers interact with the environmental system components. These environmental managers actively manipulate the environment consciously, with the aim of improving its evolution in a socio-economic and environmental complex context. Environmental managers are state or non-state, and also interact with each other [7].

Environmental management System (EMS) is a group of procedures, rules, and evidences that an organization establishes to minimize the environmental impacts produced in the development of its activity [8]. These EMSs are used widely by many companies around the world [9-11]. EMS are often based on the standard ISO 14001:2015 [12] as a tool for proactive environmental management [13, 14]. ISO 14001:2015 holds the necessary basic requirements that every environmental management system must follow with a focus on continuous and systematic improvement. It is used by organizations that look to enhance their environmental performance by complying with their environmental policy, objectives, and responsibilities. In this way, organizations contribute to strengthening the environmental pillar of sustainability [15]. EMS usually responds to ethical and competitive motivations from organizations boards [16].

Many authors showed that the implementation of EMS generates economic, operational, and environmental benefits for companies [17-19]. Other research indicate EMS has been used to create economic value, cost savings and boost market share instead of achieving environmental improves [20, 21], or has been used as a marketing too [22].

The EMS implementation results indicate a positive relationship between the environmental practices that a food company engages and its operations performance [9, 23].

Several research about wine industry show that as an agricultural sector is increasingly being challenged to reduce its environmental impact and enhance sustainability practices [24-26]. In response to these demands, wineries are turning to EMS such as ISO 14001:2015 to guide their efforts [9, 27, 28]. ISO 14001:2015 provides wineries with a comprehensive framework for effective EM, encompassing practices ranging from vineyard management to packaging and distribution [29].

ISO 14001:2015 offers wineries a structured approach to environmental management, comprising various key components. One essential aspect is the establishment of an environmental policy that outlines the winery's commitment to compliance with environmental regulations and continual improvement [30]. This policy serves as a guiding document for setting environmental objectives and targets.

To ensure effective implementation, wineries must conduct a thorough assessment of their environmental aspects and impacts [31]. This involves identifying activities, products, and services that have significant environmental effects and evaluating their potential consequences on air and water quality, energy consumption, waste generation, and biodiversity.

Once the environmental aspects and impacts are determined, wineries can develop operational controls to mitigate risks and reduce environmental harm. Examples of these controls include implementing energy-efficient practices, adopting sustainable farming techniques, promoting water conservation measures, and utilizing eco-friendly packaging materials [32-36].

ISO 14001:2015 also emphasizes the importance of employee involvement and awareness in environmental management [37]. Wineries are encouraged to provide training programs to enhance employees' understanding of environmental issues, their roles in achieving environmental objectives, and the significance of complying with environmental policies and procedures [38].

Furthermore, ISO 14001:2015 requires wineries to establish mechanisms for monitoring and measuring their environmental performance. This entails regular data collection, analysis, and reporting on key environmental indicators such as energy consumption, water usage, waste generation, and greenhouse gas emissions. By tracking their performance, wineries can identify areas for improvement and take corrective actions when necessary [39].

Effective communication and engagement with stakeholders are also integral to ISO 14001:2015 implementation. Wineries are encouraged to involve suppliers, customers, and local communities in their environmental management efforts, fostering partnerships and promoting transparency [12].

ISO 14001:2015 places a strong emphasis on continual improvement. Wineries are expected to regularly review their environmental performance, assess their progress towards achieving objectives, and identify opportunities for further enhancement. This iterative process ensures that wineries are consistently striving for improved environmental outcomes [30].

The benefits of ISO 14001:2015 implementation extend beyond environmental performance. It can also have positive economic impacts for wineries. Studies have shown that ISO 14001 certification can enhance market access, increase competitiveness, and improve financial performance [40].

Within this framework, the primary objective of this research is to evaluate the effectiveness of wineries in EM through their performance in aspects related to environmental communication, environmental commitment, environmental planning, and environmental training. Additionally, the study aims to develop a methodology for evaluating their advancement, incorporating the use of performance indicators. Furthermore, the study aims to identify the challenges that impede achieving adequate EM.

2. Materials and Methods

2.1 Study Design

Research design was proposed by conducting a questionnaire and its subsequent analysis using appropriate statistical methods. The sample was selected among Italian wineries from different wine regions. From June to November of 2022, the survey was conducted, and then, SPSS Windows software SPSS (IBM Corp. 2020. IBM SPSS Statistics v 27.0. Armonk, NY, USA) and Excel (Microsoft Corp. 2021. MS Excel v 18.0. Redmond, Washington, USA) were used to analyse the data. The calculated statistics were frequencies and central position values. Cross-Tables for categorical variables was calculated. Nonparametric tests were performed obtaining the Spearman correlation coefficient (ρ) and Kendall's Tau coefficient (τ) for nonparametric data, with a significance level of $p < 0.01$. Nonparametric Mann-Whitney U Test for two independent samples were applied, with a significance level of $p < 0.05$.

2.2. Sample Selection

Italy had 37,298 wine farms in Italia in 2021 [41]. Italian wines production amounted to 54,005 million hectolitres as of April 2023, mainly in Veneto region (11,870) and Puglia region (10,846), Emilia-Romagna region (6,139) and Sicilia (5,881) [42].

The sector main characteristics regarding to farm size are high segmentation and deep duality. Four percent of all wineries have a vineyard production area of more than 30 hectares, and together account for more than twenty-four percent of the total wine-growing area. On the contrary, there are fifty-five percent of wine farms with an area of less than 3 hectares, and which constitute seventeen percent of the total wine area [43]. So, there is a co-existence between firms that have a big wine production amount, and, in the other hand, thousands of small wine farms that have a small grapes production, usually for self-consumption.

A sample of one hundred and twenty wineries were selected from several Italian WPDOs. The sampling method selection was the non-probabilistic method [44, 45]. Researchers used earlier information to make the sample selection, instead of random selection.

Wineries were asked about their environmental management systems performance. The questionnaire was made with Google forms software [46]. Each winery received the questionnaire by email twice since May to November 2022. Survey was fulfilled by fifty-four wineries.

2.3 Survey Preparation

The design of the survey was carried out through a questionnaire with a total of thirty-two questions divided into twelve sections. Questions (Qs) were made based on ISO 14001:2015 content and research studies about EMS implementation and environmental impacts in Italian wine production [31, 40, 47-53]. Twenty-nine Qs were closed, that is, the answer alternatives were limited, and three questions were opened, which allowed a long explanation or description by the respondent. The questionnaire has been included in Appendix A. Research that are causal, descriptive, and conclusive use this kind of questionaries [54]. In addition, a Likert scale [47, 55] was utilized, incorporating both a qualitative scale and a V_Q to measure and assess the performance of wineries.
Characterizing and classifying wineries was achieved by utilizing four Qs, denoted as QS1.1, QS1.2, and QS1.3. Question QS1.1 had seven multiple-choice options and was designed to collect information concerning the role of the individual within the winery who responded to the survey. QS1.2 comprised five multiple-choice options and was aimed to evaluate the annual wine production of the wineries. The wineries' production capacities were categorized into six distinct groups based on their yearly output: less than 50,001 L/year, between 50,001-100,000 L/year, between 100,001-200,000 L/year, between 250,001-1,000,000 L/year, and more than 1,000,000 L/year. QS1.3 had four multiple-choice options and was designed to collect data related to the number of employees working at the wineries. Employee groups were classified into four ranges: less than 10, between 10-49, between 50-249, and more than 250.
Effectiveness of wineries in communicating their goals, objectives, results, and environmental commitments to all stakeholders was assessed using three Qs. QS2.3 included six multiple-choice options that inquired about the internal environmental communication strategy of wineries. In this case, V_{S23} was the quantitative variable (V_Q), and each of the multiple-choice options was assigned discrete values of 0.167, representing the primary internal communication methods employed by wineries. QS2.4 had six multiple-choice options that focused on the external environmental communication strategy concerning the winery's environmental management system. V_{S24} was the V_Q, and each multiple-choice options were assigned discrete values of 0.167, representing the key environmental areas for external communication in wineries. QS2.5 consisted of six multiple-choice options that explored how wineries conveyed their environmental information to stakeholders. V_{S25} was the V_Q, and each multiple-choice option was assigned discrete values of 0.167, representing the primary stakeholders involved in wineries' environmental communication.
Primary environmental objectives of wineries were evaluated with two multiple-choice Qs. QS2.1 comprised nine multiple-choice options and inquired about the wineries' primary environmental objectives. V_{S21} was the corresponding V_Q, with each multiple-choice item carrying discrete values of 0.112, reflecting the primary environmental objectives of the wineries. QS2.2 had nine multiple-choice options, which focused on the specific areas within the winery associated with EM. V_Q was designated as V_{S22}, and, like the previous question, each multiple-choice option was assigned discrete values of 0.112, signifying the main environmental areas within the wineries.
The role of top management and its commitment to environmental performance, as well as the allocation of staff responsible for managing the environmental system within the winery, were addressed through four Qs labelled QS3.1, QS3.2, QS3.3, and QS3.4.
QS3.1 were dichotomous question, focused on the clarity of the identification of senior environmental management within the winery. The corresponding V_Q, denoted as V_{S31},

adopted discrete values: “No” = 0 and “Yes” = 1. QS3.2 was a question with a set of four multiple-choice options designed to assess how frequently senior management reviewed the EMS. V_{S32} was the corresponding V_Q for this section, with each multiple-choice option having discrete values of 1 (“at least every six months”), 0.75 (“more than once a year”), 0.50 (“annually”), and 0 (“never reviewed”). Dichotomous QS3.3 inquired whether the winery had implemented processes to achieve annual environmental results. V_Q for this question, V_{S33}, had discrete values of “No” = 0 and “Yes” = 1. QS3.4 consisted in a question with seven multiple-choice options concerning the individual responsible for EM within the winery. The corresponding V_Q, VS34, used discrete values of 0.143, representing different staff roles.

Formulation of the environmental policy, the strategies for its communication, the specific content within the environmental policy, and its integration with the product life cycle were investigated using QS4.1, QS4.2, QS4.3, and QS4.4. Dichotomous question QS4.1 addressed the formal establishment of the winery's environmental policy. The corresponding V_Q, referred to as V_{S41}, took on discrete values of 0 for "No" and 1 for "Yes. QS4.2 had eight multiple-choice options, which focused on the different methods of disseminating the environmental policy. V_Q was designated as V_{S42}, and each multiple-choice option was assigned discrete values of 0.125. Also, QS4.3 had eight multiple-choice options, focused on different environmental commitments to be included in the environmental policy. V_Q was designated as V_{S42}, and each multiple-choice option was assigned discrete values of 0.125. QS4.4 was a question with three multiple-choice options aimed at determining which aspects of the life cycle are included in the environmental policy. V_Q was designated as V_{S44}, and each multiple-choice item was assigned discrete values of 0.334.

Evaluation of key environmental aspects in the winemaking process was carried out using three open-ended Qs. QS5.1 asked about the winery energy consumption and the measures to reduce it. Winemaking waste management performance was asked in question QS5.2. Finally, question QS5.3 asked about fermentation emissions and the way to reduce inside the winery. According to the response obtained in each open-ended answer, a "Yes" is given if the winery demonstrates performance in controlling the environmental aspect and endeavours to minimize its environmental impact. Conversely, a "No" is assigned in the opposite case. The corresponding V_Q for three Qs are V_{S51}, V_{S52} and V_{S53} and took on discrete values of 1 for "Yes" and 0 for “No”.

Implementation of the Environmental Emergency Plan (EEP) in the winery was inquired about through three Qs. Dichotomous question QS6.1 inquired on prevention or mitigation plans to act on negative environmental impact derived from an emergency. The corresponding V_Q, referred to as V_{S61}, took on discrete values of 0 for "No" and 1 for "Yes”. QS6.2 had six multiple-choice options and asked about what kind of environmental emergencies were included in those plans. V_Q was designated as V_{S62}, and each multiple-choice option was assigned discrete values of 0.167. QS6.3 had five multiple-choice options, and it asked about the periodicity at which the winery verified its EEP. V_{S63} was the corresponding V_Q, with each multiple-choice option having discrete values of 1 (“at least every six months”), 0.75 (“more than once a year”), 0.50 e di(“annually”), 0.25 (“less than once a year”), and 0 (“never”).

Document control and organization were assessed using QS7.1, QS7.2, and QS7.3. Dichotomous question QS7.1 was focused on the availability of documentary information for monitoring, measuring, and evaluating environmental performance. Corresponding V_Q, referred to as V_{S71}, took on discrete values of 0 for "No" and 1 for "Yes”. QS7.2 had five multiple-choice options and inquired about how the organization records information to demonstrate the evaluation of the effectiveness of the environmental management system. V_Q was designated as V_{S72}, and each multiple-choice option was assigned discrete values of 0.20. QS7.3 was concerned the frequency at which environmental management system documentation is created and reviewed. V_{S73} was the corresponding V_Q for this section, with each multiple-choice item having discrete values of 1 (“at least every six months”), 0.75 (“annually”), 0.50 (“more than once a year”), and 0 (“never”).

Workers´ training about environmental management was evaluated with QS8.1, QS8.2 and QS8.3. Dichotomous question QS8.1 pertained to whether wineries provide environmental management training to their employees. The corresponding V_Q, referred to as V_{S81}, took on discrete values of 0 for "No" and 1 for "Yes". QS8.2 consisted in a question of a set of four multiple-choice options designed to determine how frequently employees participate in environmental training courses. V_{S82} was the corresponding V_Q for this section, with each multiple-choice option having discrete values of 1 ("at least every six months"), 0.75 ("annually"),0.50 ("more than once a year"), and 0 ("never"). QS8.3 had a set of four multiple-choice options designed to determine the number of employees who participate in environmental training courses annually. V_{S83} was the corresponding V_Q for this section, with each multiple-choice item having discrete values of 1 ("more than 75%"), 0.75 ("between 50%-75%"), 0.50 ("between 25%-50%"), and 0.25 ("less than 25%").
Compliance with legal environmental requirements was evaluated with dichotomous QS9.2. The corresponding V_Q, denoted as V_{S92}, adopted discrete values: "No" = 0 and "Yes" = 1. Risk and opportunity assessment were evaluated with the multiple-choice QS9.3 and QS9.4. Both had three multiple-choice options. QS9.3 was a concerning the risk analysis method and QS9.4 concerning the opportunity analysis method. The corresponding VQ are VS93 and VS94 respectively, and each multiple-choice item having discrete values of 1 ("quantitative method"), 0.50 ("qualitative method"), 0 ("none").
Finally, dichotomous question QS10.1 inquires whether the EMS certification has been carried out in accordance with ISO 14001:2015 standards. The corresponding VQ, denoted as VS101, adopted discrete values: "No" = 0 and "Yes" = 1

3. Results

The distribution of wineries in descending frequencies is depicted through the Pareto chart in **Figure 1.**

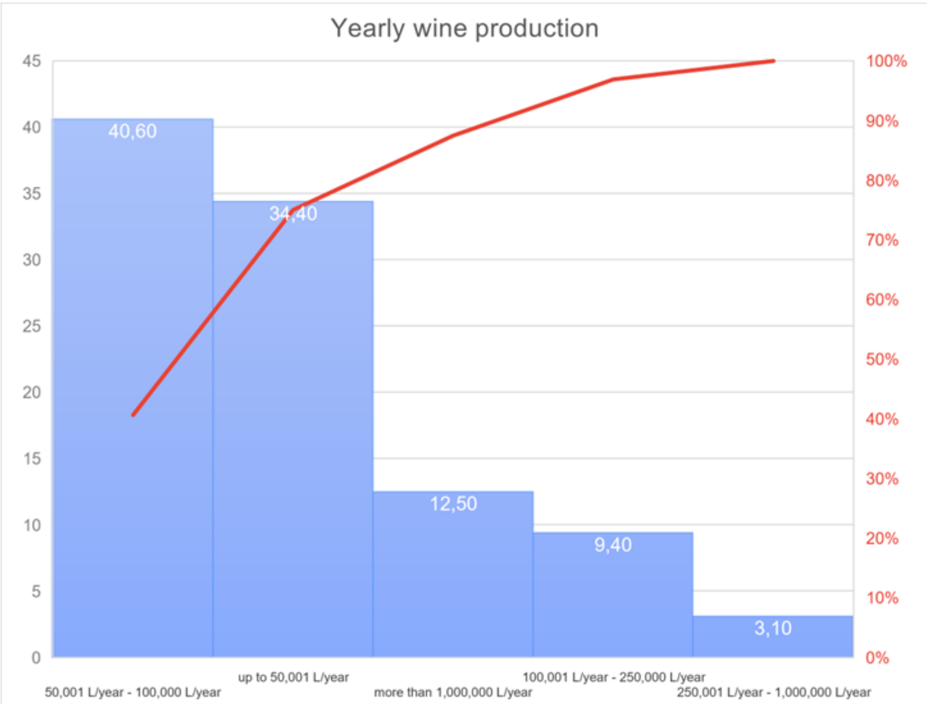

Figure 1. Wineries Pareto Chart regarding their wine yearly production

A significant majority of wineries (75.0%) produce less than one hundred thousand Liters/year, while 12.5% exceed one million Liters/year.

These wineries sample distribution stands for the Italian wine sector duality. A high number of small wineries with low annual productions and a small number of large wineries with high annual productions.

Regarding number of winery workers, 80.8% of wineries has less than 10 workers, and 19.2% have between 10 and 49 workers.

The areas related to environmental management of which the wineries claim to consider are the next: Environmental Management (48.0%), Leadership (12.0%), Planning of environmental objectives (40.0%), Environmental risk and opportunities (10.5%), Resources and environmental support (20.0%), Communication (52.0%), Operation and environmental control (40.0%), Emergency Response (12.0%) and Monitoring, analysis, and evaluation of EMS performance (52.0%). Results shows a lack of clearly define EM areas in the Italian wineries. Only large wineries (80%) have a defined an implemented structure focus on EMS.

3.1 Environmental communication

Internal communication is the way in which senior management communicates environmental issues with its staff. E-mail is used by 74.2% of wineries, being the most widespread regardless of the size of the winery. Website (45.2%) and social media (35.5%) were the next most used media. Newsletters (22.6%) and internal staff sites (12.9%) were basically used by large wineries. Finally, other ways as WhatsApp (3.2%), direct communication (6.4%) and informative talks (3.2%) are very minority systems.

External communication is harnessed by wineries to explain their environmental awareness and environmental performance to external stakeholders. 84.4% of wineries used social media as Facebook and Instagram, Website were used by 81.3% of wineries. Newsletters (31.3%), Advertisement (6.3%) and marketing campaigns (25.6%) are other minors communication ways.

Figure 2 shows the different stakeholders that wineries inform about their environmental performance and environmental awareness. Clients (88.9%) and shops (74.1%) are most popular stakeholder that received environmental information from wineries. Then, Public administrations (48.19%) and suppliers (37%). Ecology associations (3.7%) or wine club members (3.7%) are few represented.

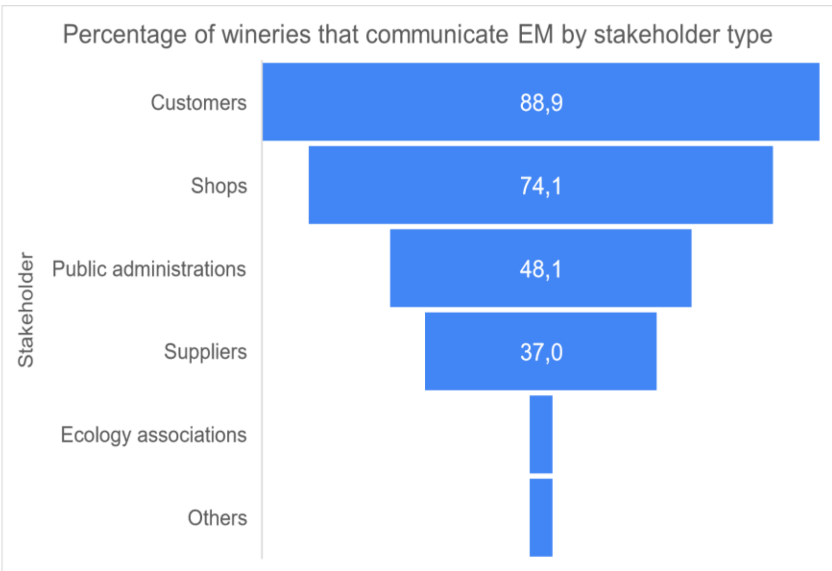

Figure 2. Percentage of wineries that communicate Environmental Management performance by stakeholder type.

Results shows that Information and Communication Technologies (ICT) [55] are clearly most often used by wineries to inform about their environmental management performance to all stakeholders, and environmental communication is focus on selling wine as customers (88.9%) and shops (74.1%) are the main target for wineries. The wineries add value to their wines by informing about an adequate environmental management, and for this they use the Social Media Marketing. Social Media Marketing (SMM) is being used to promote businesses and brands interacting with current and prospective customers through social networks. Instagram or Facebook are popular social networks that companies use to promote their products [56, 57]. One in three wineries communicate to suppliers and one in two inform to public administrations, in both cases are accomplished with the EMS communication requisites.

Finally, ecology associations or others, related to wine club members, appears as other minor stakeholder that are related to the specific contexts where wineries develop their activity.

A quantitative analysis of environmental communication was performed based on an indicator defined by the equation (1) [58, 59]:

$$\mathbf{W_{ecm}} = (\mathbf{V_{S23}} + \mathbf{V_{S24}} + \mathbf{V_{S25}} + \mathbf{V_{S42}})/\mathbf{n} \quad (1)$$

Where:

- $\mathbf{W_{ecm}}$ is the aggregated communication variable for each winery,
- $\mathbf{V_{S23}}$ is the internal communication strategy variable of the winery, $\mathbf{V_{S23}} = \sum_{j=1}^{6} \mathbf{a_j}$, $\mathbf{a_j}$ is each item of this multiple-choice question (yes=0.167, no=0),
- $\mathbf{V_{S24}}$ is the external communication strategy variable of the winery, $\mathbf{V_{S24}} = \sum_{j=1}^{6} \mathbf{b_j}$, $\mathbf{b_j}$ is each item of this multiple-choice question (yes=0.167, no=0),
- $\mathbf{V_{S25}}$ is stakeholder's variable to whom the winery communicates its environmental information of the winery, $\mathbf{V_{S25}} = \sum_{j=1}^{6} \mathbf{c_j}$, $\mathbf{c_j}$ is each item of this multiple-choice question (yes=0.167, no=0),
- $\mathbf{V_{S42}}$ is the environmental policy communication variable of the winery, $\mathbf{V_{S42}} = \sum_{j=1}^{9} \mathbf{d_j}$, $\mathbf{d_j}$ is each item of this multiple-choice question (yes=0.125, no=0),
- $\mathbf{n}$ is number of variables that has been aggregated, and its value is 4.

Obtaining the Environmental Communication Key Indicator ($\mathbf{I_{ecm}}$) for each group of wineries according to their yearly wine production size by the expression (2):

$$\mathbf{I_{ecm}} = \frac{\sum_{i=1}^{m} \mathbf{W_{ecm}}}{\mathbf{m}} \quad (2)$$

Where:

- $\mathbf{I_{ecm}}$ is the Environmental Communication Key Indicator for each group of wineries according to yearly wine production,
- $\mathbf{W_{ecm}}$ is the aggregated communication variable for each winery,
- $\mathbf{m}$ is number of wineries of the related group.

This indicator is dimensionless and express the grade of progress achieved in relation to environmental communication in each of the winery groups, according to their annual production. The grades of progress are defined as Star ($\mathbf{I_{ecm}}$ between 0-0.33), In progress ($\mathbf{I_{ecm}}$ between 0.34 -0.67), and Maturity ($\mathbf{I_{ecm}}$ between 0.68 to 1). Environmental communication indicator ($\mathbf{I_{ecm}}$) values for winery size group regarding to their yearly annual wine production are showed in **Table 5**.

3.2 Environmental commitment: Policy, leadership, and roles management

Environmental policy are organization intentions and its leadership in relation to its environmental performance. These intentions expressed and formally communicated by senior management constitute this policy *(15)*. A 71.9% of wineries had set up an environmental policy and have an environmental senior management. However, 28.1% do not have it, and this represents that one in three wineries has a big failure in its EMS. Environmental policy and senior management leadership are essential to commit the wineries with environmental protection and awareness.
Distribution of who assumed the main responsibilities for EM in the wineries is represented in **Table 1.**

Table 1. Distribution of position roles that assume EMS high responsibility in the wineries.

Position	Percentage (%)
Owner	50
Executive Manager	14
Vineyards Manager	12
General Manager	9
No answer	6
Administration Officer	3
Environmental Officer	3
Quality Advisor	3

Results highlight the significant role of owners in environmental management, with 50% of the responsibilities allocated to them. This suggests that ownership plays a crucial role in shaping the environmental policies and practices within a vineyard. Executive managers and vineyard managers follow closely, contributing 14% and 12%, respectively, showcasing their integral role in implementing and overseeing EMS. The presence of a "No answer" category at 6% suggests a potential gap in awareness or acknowledgment of environmental responsibilities among certain personnel.
Administration officers, environmental officers, and quality advisors collectively contribute 9%, indicating that specialized roles also play a significant part in ensuring EM. The distribution emphasizes the need for a holistic approach, incorporating both general management and specialized roles to address environmental challenges effectively.
Regarding to EMS reviewing by senior management, 26.9% review it at least every six months, 15.4% more than once a year, 53.8% review it annually, and 3.8% never review it. Finally, 56.3% of wineries have established procedures to achieve annual environmental results, compared to 43.8% that have not.
A quantitative measure of environmental commitment was performed based on an indicator defined by the equation (3).

$$\mathbf{W_{ecx}} = (\mathbf{V_{S41}} + \mathbf{V_{S31}} + \mathbf{V_{S32}} + \mathbf{V_{S33}})/\mathbf{n} \qquad (3)$$

Where:

- $\mathbf{W_{ecx}}$ is the aggregated commitment variable for each winery,
- $\mathbf{V_{S41}}$ is the winery environmental policy variable of the winery, (yes=1, no=0),
- $\mathbf{V_{S31}}$ is the environmental director variable of the winery (yes=1, no=0),

- $\mathbf{V_{S32}}$ measures the senior management environmental system evaluation frequency. It could take one of next four values, 1 if (at least every six months), 0.75 (more than once a year), 0.50 (annually), and 0 (never reviewed).
- $\mathbf{V_{S33}}$ is the environmental evaluation procedure variable of the winery, (yes=1, no=0).
- $\mathbf{n}$ is number of variables that has been aggregated, and its value is 4.

Obtaining the Environmental Commitment Key Indicator ($\mathbf{I_{ecx}}$) for each group of wineries according to their yearly wine production size by the equation (4):

$$\mathbf{I_{ecx}} = \frac{\sum_{i=1}^{m} \mathbf{W_{ecx}}}{\mathbf{m}} \qquad (4)$$

Where:

- $\mathbf{I_{ecx}}$ is the environmental commitment key indicator for each group of wineries according to yearly wine production,
- $\mathbf{W_{ecx}}$ is the aggregated commitment variable for each winery,
- $\mathbf{m}$ is number of wineries of the related group.

This indicator is dimensionless and express the grade of progress achieved in relation to environmental commitment and leadership in each of the winery groups, according to their annual production. The grades of progress are defined as Star ($\mathbf{I_{ecx}}$ between 0-0.33), In progress ($\mathbf{I_{ecx}}$ between 0.34 -0.67), and Maturity ($\mathbf{I_{ecx}}$ between 0.68 to 1). Environmental Commitment indicator ($\mathbf{I_{ecx}}$) values for winery size group regarding to their yearly annual wine production are showed in Table 5.

3.3 Environmental planning: Objectives, environmental aspects, risk and opportunities and legal requisites.

Environmental planning encompasses environmental objectives, environmental aspects, legal requirements related to the environment, and risk and opportunity assessment. These components together form the basis for effective environmental planning, ensuring compliance and the ongoing improvement of environmental performance.
Main wineries environmental objectives are waste production reduction (75.0%), electricity consumption reduction (75.0%), water consumption reduction (71.9%), substances releasing into the soil reduction (68.8%), greenhouse gas emissions reduction (53.1%), other gases emissions reduction (28.1%), use of raw materials reduction (21.9%), land use reduction (15.6%) and others as agricultural land recovery (3.1%).
The alignment between the long-term environmental policy commitments made by wineries and their annual environmental objectives is illustrated in Figure B1, which is provided in Appendix B for reference. In general, the greatest consistency occurs in electricity consumption (84.6%) and water consumption (83.3%), the lowest coherence occurs in fossil fuel consumption (57.9%).
The environmental aspects of the winemaking process consulted were electricity consumption ($\mathbf{V_{S51}}$), solid waste production ($\mathbf{V_{S52}}$), and gases hazardous production to workers' health ($\mathbf{V_{S53}}$). Measures used to reduce electricity consumption were installation of solar panels (50%), use of electrical energy produced by renewable sources (15%), use of buried structures to keep heat produced with electrical energy (10%) and active management of electricity consumption reduction of luminaires and equipment (10%). The 10% of wineries do not have measures to reduce electricity consumption. Measures used to reduce waste production are waste classification and separated disposal (71.4%), recycling and reuse of packaging (23.8%), use of biodegradable ecological packaging (4.72%), agronomic use of organic waste (4.7%). 4.7% of wineries do not have measures to reduce waste production.

The 61.3% of wineries adhere to the stipulated legal requirements set forth by relevant authorities regarding environmental impact. Prioritizing compliance with environmental regulations is pivotal for wineries. By systematically identifying and assessing applicable legal requirements, over half of the wineries showcase a dedicated commitment to environmental responsibility.

The 68.8% of wineries have certified their EMS according to the ISO 14001:2015 standard. This certification guarantees legal compliance, resource efficiency, and waste reduction. Demonstrating a commitment to environmental responsibility, more than half of the wineries aim to build trust and capitalize on business opportunities in environmentally conscious markets.

A quantitative measure of environmental planning was performed based on an indicator defined by the equation (5).

$$\mathbf{W_{epx}} = (\mathbf{V_{S21}} + \mathbf{V_{S22}} + \mathbf{V_{S43}} + \mathbf{V_{S44}} + \mathbf{V_{S51}} + \mathbf{V_{S52}} + \mathbf{V_{S53}} + \mathbf{V_{S92}} + \mathbf{V_{S93}} + \mathbf{V_{S94}})/\mathbf{n} \quad (5)$$

Where:

- $\mathbf{W_{epx}}$ is the aggregated environmental management planning variable for each winery,
- $\mathbf{V_{S21}}$ measures the wineries' primary environmental objectives of the winery, $\mathbf{V_{S21}} = \sum_{j=1}^{9} \mathbf{b_j}$, $\mathbf{b_j}$ is each item of this multiple-choice question (yes=0.112, no=0),
- $\mathbf{V_{S22}}$ is the EM specific areas variable of the winery, $\mathbf{V_{S22}} = \sum_{j=1}^{9} \mathbf{b_j}$, $\mathbf{b_j}$ is each item of this multiple-choice question (yes=0.112, no=0),
- $\mathbf{V_{S43}}$ is the environmental commitments variable of the winery, $\mathbf{V_{S43}} = \sum_{j=1}^{8} \mathbf{b_j}$, $\mathbf{b_j}$ is each item of this multiple-choice question (yes=0.125, no=0),
- $\mathbf{V_{S44}}$ is the life cycle aspects variable, $\mathbf{V_{S44}} = \sum_{j=1}^{3} \mathbf{b_j}$, $\mathbf{b_j}$ is each item of this multiple-choice question (yes=0.334, no=0),
- $\mathbf{V_{S51}}$ is the winery energy consumption environmental aspect variable of the winery, (yes=1, no=0),
- $\mathbf{V_{S52}}$ is the waste management performance environmental aspect variable of the winery (yes=1, no=0),
- $\mathbf{V_{S53}}$ is the fermentation emissions performance environmental aspect variable of the winery (yes=1, no=0),
- $\mathbf{V_{S61}}$ is the EEP availability variable of the winery (yes=1, no=0),
- $\mathbf{V_{S62}}$ measures the kind of emergencies in the EEP of the winery, $\mathbf{V_{S62}} = \sum_{j=1}^{6} \mathbf{b_j}$, $\mathbf{b_j}$ is each item of this multiple-choice question (yes=0.167, no=0),
- $\mathbf{V_{S63}}$ measures the EEP evaluation frequency. It could take one of next four values, 1 if (at least every six months), 0.75 (more than once a year), 0.50 (annually), and 0 (never reviewed).
- $\mathbf{V_{S71}}$ is the EMS document availability variable of the winery, (yes=1, no=0),
- $\mathbf{V_{S72}}$ measures how the EMS information is recorded in the winery, $\mathbf{V_{S72}} = \sum_{j=1}^{5} \mathbf{b_j}$, $\mathbf{b_j}$ is each item of this multiple-choice question (yes=0.2, no=0),
- $\mathbf{V_{S73}}$ measures the document control frequency. It could take one of next four values, 1 if (at least every six months), 0.75 (annually), 0.50 (more than once a year), and 0 (never reviewed).
- $\mathbf{V_{S92}}$ is the legal environmental requirements variable of the winery (yes=1, no=0),
- $\mathbf{V_{S93}}$ is the risk assessment variable. It could take one of next three values, 1 if (quantitative method), 0.50 (qualitative method), and 0 (none).
- $\mathbf{V_{S94}}$ is the opportunity assessment variable. It could take one of next three values, 1 if (quantitative method), 0.50 (qualitative method), and 0 (none).
- $\mathbf{n}$ is number of variables that has been aggregated, and its value is 10.

Obtaining the Environmental Planning Key Indicator ($\mathbf{I_{epx}}$) for each group of wineries according to their yearly wine production size by the expression (6):

$$\mathbf{I_{epx}} = \frac{\sum_{i=1}^{m} \mathbf{W_{epx}}}{\mathbf{m}} \qquad (6)$$

Where:

- $\mathbf{I_{epx}}$ is the environmental planning key indicator for each group of wineries according to yearly wine production,
- $\mathbf{W_{epx}}$ is the environmental management framework variable for each winery,
- $\mathbf{m}$ is number of wineries of the related group.

This indicator is dimensionless and express the grade of progress achieved in relation to environmental planning in each of the winery groups, according to their annual production. The grades of progress are defined as Star ($\mathbf{I_{epx}}$ between 0-0.33), In progress ($\mathbf{I_{epx}}$ between 0.34 -0.67), and Maturity ($\mathbf{I_{epx}}$ between 0.68 to 1). Environmental Planning Indicator ($\mathbf{I_{epx}}$) values for winery size group regarding to their yearly annual wine production are showed in Table 5.

3.4 Other environmental management requirements: Environmental emergency plan, document control and organization, and certification.

Other environmental requirements are based on the development of EEP, the implementation of a documented management system, and certification. This framework provides a solid foundation for environmental management and continuous improvement of environmental performance.
EEP in wineries is crucial for safeguarding human and environmental resources. Wineries face various potential emergencies, such as fires and chemical spills, which can impact their operations and the environment. The 38.7% of wineries have not formulated an EEP to prevent or mitigate adverse environmental impacts arising from emergency situations, leaving the remaining 61.3% with EEP in place. When it comes to the periodic assessment of EEP, over half of the wineries conduct these assessments annually. **Table 2** provides insight into the frequency with which wineries verify their EEPs, categorized by winery size groups.

Table 2. Percentage of wineries by size groups according with the frequency that they verify their EEP.

	Periodicity verified EEP (%)				
Wineries size	at least very six months	more than once a year	annually	less than once a year	never
Up to 50,000 L/y	8	8	58	0	25
50,001-100,000 L/y	0	0	62	16	31
100,001-250,000 L/y	0	25	75	0	0
250,001-1,000,000 L/y	0	0	100	0	0
More than 1,000,000 L/y	25	0	50	0	25

Regarding the inclusion of environmental emergencies in EEPs, data reveals that fire is a component in 86.4% of winery EEPs. An uneven discharge of water is incorporated into 45.5% of EEPs, while an unusual presence of stains or foams of un-known origin from nearby water channels is considered in 18.2% of these plans. The presence of waste and/or abandoned waste is addressed in 54% of EEPs, and the spillage of hazardous substances is a part of 22.7% of these plans. Additionally, other types of environmental emergencies are accounted for in 4.5% of winery EEPs.

Ninety-four-point twelve percent (94.12%) of wineries implement an organized and controlled documentation system. The 53% annually update information in line with ISO 14001 standard. Yet, 30% of wineries do not engage in the annual updating process.

With respect to ISO 14001:2005 certification, 31.3% of wineries have obtained certification for their Environmental Management Systems (EMS) according to this standard.

A quantitative measure of other environmental requirements was performed based on an indicator defined by the equation (7).

$$\mathbf{W_{erx}} = (\mathbf{V_{S61}} + \mathbf{V_{S62}} + \mathbf{V_{s63}} + \mathbf{V_{S71}} + \mathbf{V_{S72}} + \mathbf{V_{S73}} + \mathbf{V_{S101}}) +/\mathbf{n} \qquad (7)$$

Where:

- $\mathbf{W_{erx}}$ is the aggregated other environmental requirements variable for each winery,
- $\mathbf{V_{S61}}$ is the EEP availability variable of the winery (yes=1, no=0),
- $\mathbf{V_{S62}}$ measures the kind of emergencies in the EEP of the winery, $\mathbf{V_{S62}} = \sum_{\mathbf{j=1}}^{\mathbf{6}} \mathbf{b_j}$, $\mathbf{b_j}$ is each item of this multiple-choice question (yes=0.167, no=0),
- $\mathbf{V_{S63}}$ measures the EEP evaluation frequency. It could take one of next four values, 1 if (at least every six months), 0.75 (more than once a year), 0.50 (annually), and 0 (never reviewed).
- $\mathbf{V_{S71}}$ is the EMS document availability variable of the winery, (yes=1, no=0),
- $\mathbf{V_{S72}}$ measures how the EMS information is recorded in the winery, $\mathbf{V_{S72}} = \sum_{\mathbf{j=1}}^{\mathbf{5}} \mathbf{b_j}$, $\mathbf{b_j}$ is each item of this multiple-choice question (yes=0.2, no=0),
- $\mathbf{V_{S73}}$ measures the document control frequency. It could take one of next four values, 1 if (at least every six months), 0.75 (annually), 0.50 (more than once a year), and 0 (never reviewed).
- $\mathbf{V_{S101}}$ is the legal environmental requirements variable of the winery (yes=1, no=0),
- $\mathbf{n}$ is number of variables that has been aggregated, and its value is 7.

Obtaining the Other Environmental Management Requirements Key Indicator ($\mathbf{I_{erx}}$) for each group of wineries according to their yearly wine production size by the expression (8):

$$\mathbf{I_{erx}} = \frac{\sum_{\mathbf{i=1}}^{\mathbf{m}} \mathbf{W_{erx}}}{\mathbf{m}} \qquad (8)$$

Where:

- $\mathbf{I_{erx}}$ is the other environmental management requirements key indicator for each group of wineries according to yearly wine production,
- $\mathbf{W_{erx}}$ is the other environmental management requirements variable for each winery,
- $\mathbf{m}$ is number of wineries of the related group.

This indicator is dimensionless and express the grade of progress achieved in relation to other environmental requirements in each of the winery groups, according to their annual production. The grades of progress are defined as Star ($\mathbf{I_{erx}}$ between 0-0.33), In progress ($\mathbf{I_{erx}}$ between 0.34 -0.67), and Maturity ($\mathbf{I_{erx}}$ between 0.68 to 1). Other Environmental Management Requirements indicator ($\mathbf{I_{erx}}$) values for winery size group regarding to their yearly annual wine production are showed in **Table 5.**

3.4 Environmental training for workers

Employee training in environmental management is pivotal in raising awareness about environmental aspects within their roles and responsibilities. This training encompasses understanding sustainable objectives and activities, thereby contributing to the continuous improvement of environmental performance.

The 71% percent of wineries provide training to their employees in connection with their environmental management system, whereas the remaining 29% do not offer such training. **Table 3** illustrates the distribution of training offerings based on winery size.

Table 3. Percentage of wineries that offer training to their workers categorized by their annual wine production size.

	% of wineries that offer environmental training to their workers				
Wineries size	Up to 50,000 L/year	50,001-100,000 L/year	100,001-250,000 L/year	250,001-1,000,000 L/year	More than 1,000,000 L/year
Percentage	42	69	75	100	100

The frequency of worker participation in environmental training courses and the percentage of total workers participating in such courses annually, categorized by winery size, is showed in **Table 4.**

Table 4. Percentage data regarding the frequency of worker participation in environmental training and the percentage of total workers participating in such training annually categorized by winery size.

	% of wineries categorized according to the frequency at which their workers participate in environmental training				
Wineries size	at least every six months	annual	more than once a year	never	
Up to 50,000 L/year	0	67	33	0	100
50,001-100,000 L/year	11	78	11	0	100
100,001-250,000 L/year	0	100	0	0	100
250,001-1,000,000 L/year	0	100	0	0	100
More than 1,000,000 L/year	25	75	0	0	100
	% of wineries categorized based on the proportion of their total workforce participating in annual environmental training				
Wineries size	more than 75%	between 50%-75%	between 25%-50%	less than 25%	
Up to 50,000 L/year	17	0	67	16	100
50,001-100,000 L/year	56	0	11	33	100
100,001-250,000 L/year	34	33	33	0	100
250,001-1,000,000 L/year	100	0	0	0	100
More than 1,000,000 L/year	75	0	25	0	100

A quantitative measure of environmental workers´ training was performed based on an indicator defined by the equation (9).

$$\mathbf{W_{ewt}} = (\mathbf{V_{S81}} + \mathbf{V_{S82}} + \mathbf{V_{S83}})/\mathbf{n} \qquad (9)$$

Where:

- $\mathbf{W_{ewt}}$ is the aggregated environmental worker training variable for each winery,
- $\mathbf{V_{S81}}$ is the EMS workers training availability variable of the winery (yes=1, no=0),
- $\mathbf{V_{S82}}$ measures the workers training frequency. It could take one of next four values, 1 if (at least every six months), 0.75 (annually), 0.50 (more than once a year), and 0 (never).
- $\mathbf{V_{S83}}$ measures number of employees who participate in environmental training courses annually. It could take one of next four values of 1 (more than 75%), 0.75 (between 50%-75%), 0.50 (between 25%-50%), and 0.25 (less than 25%).
- $\mathbf{n}$ is number of variables that has been aggregated, and its value is 3.

Obtaining the Environmental Workers Training Key Indicator ($\mathbf{I_{ewt}}$) for each group of wineries according to their yearly wine production size by the equation (10):

$$\mathbf{I_{ewt}} = \frac{\sum_{i=1}^{m} \mathbf{W_{ewt}}}{\mathbf{m}} \qquad (10)$$

Where:

- $\mathbf{I_{ewt}}$ is the environmental workers training key indicator for each group of wineries according to yearly wine production,
- $\mathbf{W_{ewt}}$ is the aggregated environmental workers training variable for each winery,
- $\mathbf{m}$ is number of wineries of the related group.

This indicator is dimensionless and express the grade of progress achieved in relation to environmental workers training in each of the winery groups, according to their annual production. The grades of progress are defined as Star ($\mathbf{I_{ewt}}$ between 0-0.33), In progress ($\mathbf{I_{ewt}}$ between 0.34 -0.67), and Maturity ($\mathbf{I_{ewt}}$ between 0.68 to 1). Environmental Workers Training Indicator ($\mathbf{I_{ewt}}$) values for winery size group regarding to their yearly annual wine production are showed in Table 5.

3.5 Integrated table and graph of the grade of progress in wineries generated by the performance indicators.

Effectiveness in EM is achieved through the combination of five components: communication, commitment, planning, other requirements, and workers training. The five performance key indicators allow to determine the degree of progress that each group of wineries has reached related to EM performance. **Table 2** and **Table 5** shows values $\mathbf{I_{ecm}}$, $\mathbf{I_{ecx}}$, $\mathbf{I_{epx}}$, $\mathbf{I_{erx}}$ and $\mathbf{I_{ewt}}$ by winery sizes groups and grade of progress.
Each key performance indicator represents the level of progress in a specific component. $\mathbf{I_{ecm}}$ stands as the performance metric reflecting advancements in the communication component. $\mathbf{I_{ecx}}$ serves as the indicator representing progress in the commitment component, $\mathbf{I_{epx}}$ denotes the metric showing progress in the environmental planning component, $\mathbf{I_{erx}}$ serves as a metric indicating progress in the implementation of other EM requirements, and $\mathbf{I_{ewt}}$ signifies the indicator reflecting progress in the training component. Components performance level by each winery sizes group on EM are illustrated in **Figure 3**.

Table 5. Environmental Communication Key Indicator (**I_{ecm}**), Environmental Commitment Key Indicator (**I_{ecx}**), Environmental Planning Key Indicator (**I_{epx}**), Environmental Management Requirements Key Indicator (**I_{erx}**) and Environmental Workers Training Key Indicator (**I_{ewt}**) values by winery sizes groups and their corresponding grade of performance progress performance.

Wineries size	I_{ecm}	Grade of progress	I_{ecx}	Grade of progress	I_{epx}	Grade of progress	I_{erx}	Grade of progress	I_{ewt}	Grade of progress
Up to 50,000 L/year	0.29	Star	0.55	In progress	0.40	In progress	0.44	In progress	0.38	In progress
50,001-100,000 L/year	0.33	Star	0.65	In progress	0.53	In progress	0.45	In progress	0.83	Maturity
100,001-250,000 L/year	0.36	In progress	0.66	In progress	0.56	In progress	0.67	In progress	0.63	In progress
250,001-1,000,000 L/year	0.35	In progress	0.90	Maturity	0.77	Maturity	0.77	Maturity	0.92	Maturity
More than 1,000,000 L/year	0.46	In progress	0.83	Maturity	0.98	Maturity	0.66	In progress	0.90	Maturity

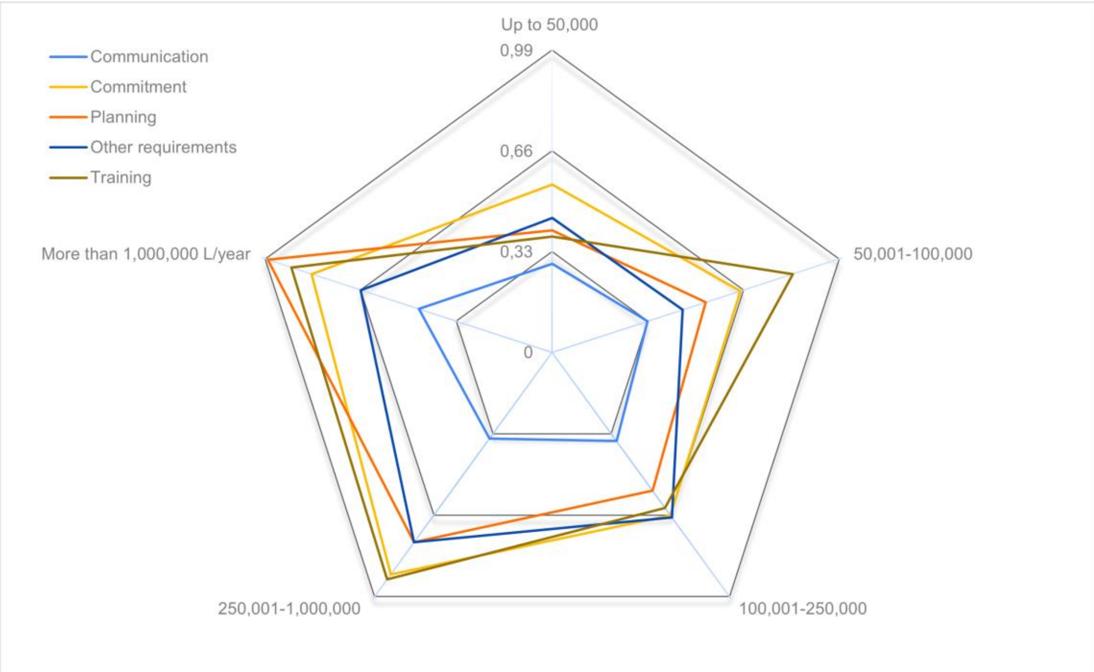

Figure 3. Radial diagram with each EM components performance by each winery sizes group.

4. Discussion

Our investigation has unearthed essential insights into the EM practices within Italian wineries, delving into their environmental objectives, communication tactics, and adherence to environmental policies and leadership frameworks. Mirroring the findings of Nishitani K., our research underscores the profound influence that EMS exert on a firm environmental performance [60]. The Italian wine sector, driven by EU regulations and a consumer demand for eco-friendly products, has increasingly adopted EMS, focusing on minimizing water and energy consumption and reducing chemical use. This shift towards sustainability is evidenced by the wine industry pursuit of environmental certifications, such as ISO 14001, aligning with Nishitani observations on EMS beneficial impact on EMS in the environmental performance, as discussed by Martin-de Castro in 2016 [61].

Regarding the scale of winery operations, a significant majority, 80.8%, employ less than ten individuals. This distribution by workforce size is crucial, potentially impacting their approach to environmental management. Smaller wineries, constrained by their scale, often encounter difficulties in implementing advanced sustainable technologies. Research by Gabzdylova [62] reveals a keen interest in sustainable practices, hindered by financial limitations, restricted sustainability information, and the complexity of EMS implementation. This reflects our findings on how the size of winery farms influences EM strategies, with smaller entities facing challenges in making substantial sustainability investments. However, smaller wineries have the advantage of targeting niche markets that value sustainability and artisanal methods. A study on New Zealand wineries markets by Forbes [63] illustrates how they leverage their small scale to market their wines as premium, often using sustainability as a unique selling proposition, allowing them to stand out in a competitive market.

Conversely, larger agricultural firms have shown their capability to initiate significant environmental projects. Examples from Brazil's soybean and beef industries, and the food manufacturing EU sector, as highlighted by Medina [64], demonstrate the potential of larger enterprises to set sustainability standards and influence industry practices.

Environmental objectives are a focal point for wineries, aiming for reductions in waste, electricity, and water use, and emissions. However, there's variability in how these long-term commitments align with annual goals, particularly concerning fossil fuel usage. Rahman research [65] provides insights into the challenges and opportunities within the wine industry, noting the positive correlation between electricity consumption, economic growth, and CO2 emissions, and the negative impact of globalization on emissions. In regions like California, the adoption of renewable energy sources by wineries, exemplified by the Napa Green program, marks a significant step towards reducing non-renewable electricity dependence [66].

The domain of environmental communication is pivotal, utilizing both internal and external channels. Internal communication heavily relies on email, used by 74.2% of wineries, underscoring the digital platform's ubiquity. Externally, social media, especially Facebook and Instagram, play a significant role, with 84.4% of wineries using them to share their environmental initiatives with stakeholders. This proactive use of ICT for environmental management communication is supported by Galati [67] in 2019, which found that wineries most active in social responsibility and engagement on social media platforms have a marked impact on information dissemination. Clients (88.9%) and shops (74.1%) are most popular stakeholder that received environmental information from wineries. These data underscores wineries' commitment to reaching their customers and shops, which constitute the main target audience for their environmental communication efforts. This result corresponds with the growing interest of wine consumers in environmental issues, as demonstrated in various studies [68, 69] different stakeholders that wineries inform about their environmental performance and environmental awareness. However, there is room for growth in connecting with specific stakeholder groups such as ecology associations and wine club members. These segments are relatively underrepresented in wineries' environmental communication strategies, presenting an opportunity for further engagement.

Environmental commitment are foundational aspects in environmental awareness. Approximately 71.9% of wineries have established environmental policies, indicating a solid commitment to environmental stewardship. However, the existence of wineries without such policies, about 28.1%, reveals gaps in EMS adoption. The role of senior management in fostering environmental responsibility is critical, with more than half of the wineries undertaking annual EMS reviews, although a small percentage, 3.8%, never review their EMS, highlighting varied commitment levels across the industry. These findings align with research by Burawat [70], underscoring the impact of leadership on sustainable practices. Responsibility distribution for environmental management in viticulture places owners, executive managers, and vineyard managers at the forefront of implementing sustainability measures. The presence of a "No answer" category emphasizes the need for awareness and accountability across management levels. Our environmental commitment indicator offers a metric for assessing progress in EM among wineries, reflecting their dedication to environmental responsibility based on annual wine production.

This commitment is manifested in various environmental goals, such as waste reduction and lower electricity and water usage, and aligned with Fragoso research [71] on primary environmental objectives in Portuguese wineries. However, alignment between long-term commitments and annual targets, especially regarding fossil fuel consumption, needs improvement. The winemaking process involves strategies to reduce electricity usage and waste production, with a notable interest in sustainable practices highlighted by similar research from Iannone [72] in 2021, and Zhang [73] in 2019. Measures primarily include waste classification and disposal (71.4%) and the recycling and reuse of packaging materials (23.8%). A notable 4.7% of wineries utilize agronomic practices for organic waste, indicating an increasing interest in sustainable methods.

Emergency preparedness remains vital, with 38.7% of wineries lacking comprehensive plans, though the majority conduct periodic assessments. Preparedness for fire emergencies is robust in our findings. Our results align with the requirements related to emergency preparedness in food businesses as identified by Song [74]. Song indicated that improving technology, employee skills, and process monitoring enhances effective emergency preparedness in food businesses.

Nearly all wineries prioritize organizing and controlling documentation, essential for aligning with ISO 14001 standards and demonstrating commitment through the documentation system. However, a third of wineries do not update their documentation annually, indicating an area for improvement.

The level of EMS certification to the ISO 14001:2015 standard is relatively low, consistent with findings in the Italian wine sector [75, 76].

Data emphasizes the significance of environmental training in wineries supporting research that shows workers environmental responsibility and personal values drive sustainable behaviour and innovation [77, 78]. It also sheds light on trends based on winery size and annual wine production. Notable findings include information about winery size and training provision revealing correlation between winery size and the provision of environmental training. Larger wineries universally offer environmental training to their employees. This underscores the commitment of larger establishments to employee training in environmental management. Findings demonstrate that the frequency of worker participation in environmental training varies among wineries of different sizes. This divergence underscores the diversity of training approaches based on winery size. Results are consistent with the findings about winery workers training conducted by Lopez-Santiago [79].

Several factors can influence engagement levels in environmental training across wineries of different sizes. For large wineries, the availability of resources to invest in comprehensive training programs, along with a formalized organizational structure, likely contributes to higher engagement levels. In contrast, small wineries may struggle with resource constraints, leading to less formalized training and lower engagement. Furthermore, the culture and values of the organization, leadership commitment to environmental issues, and the perceived relevance of the training to employees' roles can significantly impact workforce engagement. Workforce engagement in environmental initiatives is increasingly recognized as a critical factor for the successful implementation of sustainable practices in the wine industry. Studies by Hameed [80] and Riyanto [81] suggest that the active involvement of employees in environmental training and sustainability programs significantly contributes to the effectiveness of these initiatives. Engaged employees are more likely to adopt and advocate for sustainable practices, leading to a more environmentally responsible organizational culture.

Environmental performance indicators developed in our study provide a benchmark for evaluating EM progress across different winery sizes, offering insights into the industry's commitment to improving its environmental footprint. These findings highlight the wine industry's diverse efforts towards sustainability, emphasizing the critical role of communication, training, and leadership in advancing environmental management practices.

4.4 Limitation and strength of the study

One of the key drawbacks of this research resides in the diminished rate of participation received from the wineries under examination, which could potentially influence the inclusiveness and applicability of the data to the broader Italian wine industry. Nonetheless, a fundamental merit of this study is grounded in the formulation of performance metrics utilizing the questionnaire approach. This instrument establishes a sturdy groundwork for scrutinizing data and facilitates the assessment of wineries' performance in EMS.

5. Conclusions

Our study has successfully achieved its primary goal by providing a detailed overview of how Italian wineries manage their environmental practices, communicate their strategies, and commit to EM. The research identified both strong points and potential areas for enhancement in their efforts towards environmental sustainability, offering a clear view of the varied strategies and dedication levels across the industry. Furthermore, it developed a collection of indicators, based on survey responses, that allows us to measure the advancement of EM adoption within wineries.

In addition to reducing environmental impacts, EMS implementation helped wineries to improve their reputation and gain a competitive advantage in the global market. Wineries that have a certified EMS could differentiate their products from other conventional wines. Despite the benefits of EMS implementation, there are also challenges and limitations to their effectiveness. One of the main challenges is the cost and complexity of implementing EMS, which can be a barrier for small and medium-sized wineries. Additionally, EMS implementation requires ongoing monitoring and evaluation to ensure that environmental goals are being met.

While existing research underscores the importance of environmental practices and workforce engagement in the wine industry, there is a noticeable gap in literature specifically addressing how the size of wineries influences engagement levels in environmental training. This gap presents an opportunity to explore the relationship between winery size and workforce engagement, particularly how small and large wineries differ in their approaches and challenges to engaging their workforce in environmental initiatives. The capacity of larger firms in the food industry to leverage economies of scale for environmental sustainability is evident across various sectors and countries. These firms play a pivotal role in advancing sustainable practices, from agriculture to manufacturing and retail. However, realizing the full potential of these initiatives requires addressing challenges related to transparency, supply chain complexity, and ensuring that sustainability efforts benefit all stakeholders within the food system.

The policy implications emphasizing the importance of technological investment, education, and global cooperation are directly applicable to the wine industry. Collaborative efforts, possibly in the form of international partnerships or certifications, could promote the sharing of sustainable practices and technologies across borders, enhancing the industry's overall sustainability. Globalization's role in environmental degradation is complex; however, implying that increased globalization can lead to improved environmental quality. In the context of wineries, globalization has facilitated the exchange of sustainable technologies and practices. New World wine-producing countries, such as New Zealand and Chile, have rapidly adopted sustainable viticulture and winemaking practices, partly due to their integration into the global wine market.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, X.X. and Y.Y.; methodology, X.X.; software, X.X.; validation, X.X., Y.Y. and Z.Z.; formal analysis, X.X.; investigation, X.X.; resources, X.X.; data curation, X.X.; writing—original draft preparation, X.X.; writing—review and editing, X.X.; visualization, X.X.; supervision, X.X.; project administration, X.X.; funding acquisition, Y.Y. All authors have read and agreed to the published version of the manuscript." Please turn to the CRediT taxonomy for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

Data Availability Statement: The data presented in this study are available upon demand from the correspondence author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Environmental management system questionnaire (Italy) * Obligatory

1. Company name*

2. E-mail address *

3. S1.1 Annual production capacity

Mark only one oval.

- o Less than 50,001 liters/year.
- o 50,001 liters/year - 100,000 liters/year.
- o 100,001 liters/year - 250,000 liters/year.
- o 250,001 liters/year – 1,000,000 liters/year.
- o More than 1,000,000 liters/year.

4. S1.2 Number of employees

Mark only one oval.

- o < 10.
- o 10 to 49.
- o 50 to 249.
- o 250.

5. S1.3 Job position in the company

Mark only one oval.

- o General Manager.
- o Owner Manager.
- o Ecological Manager.
- o Administration Officer.
- o Vineyard Manager Executive Director.
- o Other

6. S2.1 What are the company's main environmental objectives?

Select all that apply.

- o Electricity consumption reduction.
- o Water consumption reduction.
- o Land use reduction.
- o Greenhouse gas emissions reduction.
- o Other gases emissions reduction.
- o Waste production reduction.
- o Use of raw materials reduction.
- o Substances releasing into the soil reduction.
- o Other

7. S2.2 Does the company have any of the following areas/departments?

Select all that apply.

- o Environmental Management.
- o Leadership.
- o Planning of environmental objectives.
- o Environmental risk and opportunities.
- o Resources and environmental support.
- o Communication.
- o Operation and environmental control.
- o Emergency response.
- o Monitoring, analysis, and evaluation of EMS performance.

8. S2.3 What is the company's internal communication strategy?

Select all that apply.

- o Website.
- o Email.
- o Social media (Facebook, Instagram etc.).
- o Newsletters.
- o Internal staff site.
- o Other

9. S2.4 What is the company's external communication strategy?

Select all that apply.

- o Website.
- o Social media (Facebook, Instagram, etc).
- o Newsletters.
- o Advertisement.
- o Marketing campaigns.
- o Other

10. S2.5 Does the company disclose environmental information to any stakeholders?

Select all that apply.

- o Clients.
- o Ecology associations.
- o Public administrations.
- o Suppliers.
- o Shops.
- o Other

11. S3.1 Has the organization clearly identified the Environmental Director in the company?

Mark only one oval.

- o Yes.
- o No.

12. S3.2 How often does the senior management review the organization's environmental management system?

Mark only one oval.

- o At least every six months.
- o Annually.
- o Over a year.
- o Never.

13. S3.3 Has the company established processes to achieve annual environmental results?

Mark only one oval.

- o Yes.
- o No.

14. S4.1 Has the company established an environmental policy?

Mark only one oval.

- o Yes.
- o No.

15. S4.2 How does the company communicate and/or promote its environmental policy?

Select all that apply.

- o Website. Newsletter. Social Media. Advertisement.
- o E-mail promotional. Marketing campaigns.
- o Courses
- o None of these
- o Other

16. S4.3 Does the company's environmental policy include any of these commitments?

Select all that apply.

- o Reduce use of water.
- o Reduce use of fossil combustible.
- o Control of electricity use.
- o Reduce of fertilizers and pesticides use.
- o Reduce of gas emissions.
- o Increasing land use efficiency.
- o Improvement in packaging (glass bottles).

- o Improvement in wines distribution.

17. S4.4 What aspects of the life cycle are included in environmental policy?

Select all that apply.

- o Environmental impacts of the supply chain.
- o Environmental impacts of product use.
- o Environmental impacts of waste generation.

18. S3.4 Who is responsible for environmental management?

Mark only one oval.

- o Owner
- o General Manager
- o Environmental Manager
- o Administrative Manager
- o Vineyard Director
- o Executive Director
- o Other:

19. S5.1 Considering that wineries have a high energy consumption, what actions or measures does the company take to re-duce the environmental impact?

20. S5.2 Wineries generate a lot of solid waste which, once disposed of, has a high environmental impact. How is this high amount of waste managed?

21. S5.3 Wineries generate gases that are usually impregnated with fruit or machinery. What processes should be in place to reduce these emissions and therefore generate less impact?

22. S6.1 Has the company prepared plans to prevent or mitigate negative environmental impacts resulting from emergency situations?

Mark only one oval.

- o Yes.
- o No.

23. 6.2 If so, which environmental emergency is the company prepared for? (Select one or more)

Select all that apply.

- o Fire
- o Water uncontrolled discharge with cleaning product or organic matter residues.
- o Water drains with chemical contaminants.
- o Landfilling of waste and/or abandoned waste.
- o Leakage of dangerous substances.
- o Other

24. S6.3 Does the company periodically review planned response actions for emergency situations?

Mark only one oval.

- o At least every six months.
- o Annually.
- o Over a year.
- o Never.

25. S7.1 Does the organization have documented information to demonstrate that monitor, measure and evaluate its environ-mental performance?

Mark only one oval.

- o Yes.
- o No.

26. S7.2 How does the organization record information to demonstrate that it evaluates the effectiveness of its environmental management system?

Select all that apply.

- o Data records.
- o Reports.
- o Technical Instructions.
- o Procedures.
- o None of these.
- o Other.

27. S7.3 How often does the company create and update documented information consistent with its environmental manage-ment system?

Mark only one oval.

- o At least every six months.
- o Annually.
- o Over a year.
- o Never.

28. S9.2 Does the company have legal requirements from government bodies or other relevant authorities in relation to envi-ronmental impacts?

Mark only one oval.

- o Yes.
- o No.

29. S8.1 Is training offered to staff on environmental management systems?

Mark only one oval.

- Yes.
- No.

30. S8.2 If so, how often do staff take these environmental trainings?

Mark only one oval.

- At least every six months.
- Annually.
- Over a year.
- Never.

31. S8.3 How many workers have already undergone environmental management training?

Mark only one oval.

- Less than 25%
- Between 25 - 50%
- Between 50 - 75%
- More than 75%

32. S9.3 What method does the organization use to carry out risk analysis?

Mark only one oval.

- Quantitative method
- Qualitative method
- None

33. S9.4 What method does the organization use to perform the opportunity analysis?

Mark only one oval.

- Quantitative method
- Qualitative method
- None

34. S10.1 Has the company certified its EMS with ISO 14001:2015?

Mark only one oval.

- Yes.
- No.

Appendix B

			Q S2.1[a]									
			Electricity consumption reduction	Water consumption reduction	Land use reduction	Greenhouse gas emissions reduction	Other gas emissions reduction	Waste production reduction	Use of raw materials reduction	Substances releasing into the soil reduction	Others: Agricultural land recovery	Total
QS4.3[a]	Reduce use of water	Count	20	20	4	12	7	18	6	15	0	22
		% inside QS4.3	90,9%	90,9%	18,2%	54,5%	31,8%	81,8%	27,3%	68,2%	0,0%	
		% inside QS2.1	76,9%	83,3%	66,7%	63,2%	77,8%	69,2%	75,0%	65,2%	0,0%	
		% total	58,8%	58,8%	11,8%	35,3%	20,6%	52,9%	17,6%	44,1%	0,0%	64,7%
	Reduce use of fosil combustibles	Count	16	16	5	11	8	17	6	14	1	20
		% inside QS4.3	80,0%	80,0%	25,0%	55,0%	40,0%	85,0%	30,0%	70,0%	5,0%	
		% inside QS2.1	61,5%	66,7%	83,3%	57,9%	88,9%	65,4%	75,0%	60,9%	100,0%	
		% total	47,1%	47,1%	14,7%	32,4%	23,5%	50,0%	17,6%	41,2%	2,9%	58,8%
	Control of electricity use	Count	22	19	3	14	8	19	6	14	0	23
		% inside QS4.3	95,7%	82,6%	13,0%	60,9%	34,8%	82,6%	26,1%	60,9%	0,0%	
		% inside QS2.1	84,6%	79,2%	50,0%	73,7%	88,9%	73,1%	75,0%	60,9%	0,0%	
		% total	64,7%	55,9%	8,8%	41,2%	23,5%	55,9%	17,6%	41,2%	0,0%	67,6%
	Reduce of ferlizers and pesticides use	Count	22	21	5	18	8	24	7	20	0	29
		% inside QS4.3	75,9%	72,4%	17,2%	62,1%	27,6%	82,8%	24,1%	69,0%	0,0%	
		% inside QS2.1	84,6%	87,5%	83,3%	94,7%	88,9%	92,3%	87,5%	87,0%	0,0%	
		% total	64,7%	61,8%	14,7%	52,9%	23,5%	70,6%	20,6%	58,8%	0,0%	85,3%
	Reduce of gas emissions	Count	9	9	3	11	7	11	7	8	1	12
		% inside QS4.3	75,0%	75,0%	25,0%	91,7%	58,3%	91,7%	58,3%	66,7%	8,3%	
		% inside QS2.1	34,6%	37,5%	50,0%	57,9%	77,8%	42,3%	87,5%	34,8%	100,0%	
		% total	26,5%	26,5%	8,8%	32,4%	20,6%	32,4%	20,6%	23,5%	2,9%	35,3%
	Increase land use efficiency	Count	11	12	6	9	5	15	4	12	1	16
		% inside QS4.3	68,8%	75,0%	37,5%	56,3%	31,3%	93,8%	25,0%	75,0%	6,3%	
		% inside QS2.1	42,3%	50,0%	100,0%	47,4%	55,6%	57,7%	50,0%	52,2%	100,0%	
		% total	32,4%	35,3%	17,6%	26,5%	14,7%	44,1%	11,8%	35,3%	2,9%	47,1%
	Improvement in packaging (glass bottles)	Count	13	14	5	10	6	18	6	13	1	20
		% inside QS4.3	65,0%	70,0%	25,0%	50,0%	30,0%	90,0%	30,0%	65,0%	5,0%	
		% inside QS2.1	50,0%	58,3%	83,3%	52,6%	66,7%	69,2%	75,0%	56,5%	100,0%	
		% total	38,2%	41,2%	14,7%	29,4%	17,6%	52,9%	17,6%	38,2%	2,9%	58,8%
	Improvement in wines distribution	Count	6	4	1	6	3	7	2	5	0	9
		% inside QS4.3	66,7%	44,4%	11,1%	66,7%	33,3%	77,8%	22,2%	55,6%	0,0%	
		% inside QS2.1	23,1%	16,7%	16,7%	31,6%	33,3%	26,9%	25,0%	21,7%	0,0%	
		% total	17,6%	11,8%	2,9%	17,6%	8,8%	20,6%	5,9%	14,7%	0,0%	26,5%
Total		Count	26	24	6	19	9	26	8	23	1	34
		% total	76,5%	70,6%	17,6%	55,9%	26,5%	76,5%	23,5%	67,6%	2,9%	100,0%

Figure B1. Cross-table between question S2.1 and question S4.2 showing coherence between environmental poli-cy and annual environmental objectives by wineries.

References

1. Commission of the European Communities Communication from the Commission A Sustainable Europe for a Better World: A European Union Strategy for Sustainable Development (Commission's proposal to the Gothenburg European Council). Document 52001DC0264. **2001**.
2. United Nations General Assembly Transforming our world: the 2030 Agenda for Sustainable Development . *United Nations* **2015.**
3. European Commission Next steps for a sustainable European future
European action for sustainability: Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committe and The Committe of the Regions. COM(2016) 739 final. **2016**.

4. European Commission Delivering the benefits of EU environmental policies through a regular Environmental Implementation Review. Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committe and The Committe of the Regions.COM(2016) 316 final. **2016**.
5. European Union DECISION (EU) 2022/591 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 6 April 2022 on a General Union Environment Action Programme to 2030. *Official Journal of the European Union L 114; Vol.65; 22-33* **2022**.
6. European Commission The European Green Deal. Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committe and The Committe of the Regions. COM(2019) 640 final. **2019**.
7. Geoff A. Wilson & Raymond L. Bryant *Environmental management;* Roudedge. Taylor & Francis Group: New York, 1997; .
8. Barla, P. ISO 14001 certification and environmental performance in Quebec's pulp and paper industry. *Journal of environmental economics and management* **2007**, *53*, 291-306.
9. Marimon, F.; Llach, J.; Bernardo, M. Comparative analysis of diffusion of the ISO 14001 standard by sector of activity. *Journal of cleaner production* **2011**, *19*, 1734-1744.
10. To, W. M.; Lee, P. K. C. Diffusion of ISO 14001 environmental management system: global, regional and country-level analyses. *Journal of cleaner production* **2014**, *66*, 489-498.
11. Neves, F. d. O.; Salgado, E. G.; Beijo, L. A. Analysis of the Environmental Management System based on ISO 14001 on the American continent. *Journal of environmental management* **2017**, *199*, 251-262.
12. International Organization for Standardization *Environmental Management Systems: Requirements with Guidance for Use;* Intenational Organization for Standardization: 2015; .
13. Summers Raines, S. Implementing ISO 14001—An International Survey Assessing the Benefits of Certification. *Corp. Environ. Strategy* **2002**, *9*, 418-426.
14. Salim, H. K.; Padfield, R.; Hansen, S. B.; Mohamad, S. E.; Yuzir, A.; Syayuti, K.; Tham, M. H.; Papargyropoulou, E. Global trends in environmental management system and ISO14001 research. *Journal of cleaner production* **2018**, *170*, 645-653.
15. Technical Committee, ISO/TC 207/SC 1 ISO 14001-2015 Environmental Management Systems (EMS). **2015**.
16. González-Benito, J.; González-Benito, O. An analysis of the relationship between environmental motivations and ISO14001 certification. *Br. J. Manage.* **2005**, *16*, 133-148.
17. Comoglio, C.; Botta, S. The use of indicators and the role of environmental management systems for environmental performances improvement: a survey on ISO 14001 certified companies in the automotive sector. *J. Clean. Prod.* **2012**, *20*, 92-102.
18. Nishitani, K. Empirical Analysis of the Effects on Firms' Economic Performance of Implementing Environmental Management Systems. *Environ Resource Econ* **2011**, *48*, 569-586.
19. Sambasivan, M.; Fei, N. Y. Evaluation of critical success factors of implementation of ISO 14001 using analytic hierarchy process (AHP): a case study from Malaysia. *Journal of cleaner production* **2008**, *16*, 1424-1433.
20. Jones, S.; Laquidarra, D. World Green Building Trends 2018. *SmartMarket Report* **2018**.
21. Horry, R.; Booth, C. A.; Mahamadu, A.; Manu, P.; Georgakis, P. Environmental management systems in the architectural, engineering and construction sectors: a roadmap to aid the delivery of the sustainable development goals. *Environ Dev Sustain* **2022**, *24*, 10585.

22. Turk, A. M. The benefits associated with ISO 14001 certification for construction firms: Turkish case. *Journal of cleaner production* **2009**, *17*, 559-569.
23. Sroufe, R. Effects of environmental management systems on environmental management practices and operations. *Production and operations management* **2003**, *12*, 416-431.
24. Annunziata, E.; Pucci, T.; Frey, M.; Zanni, L. The role of organizational capabilities in attaining corporate sustainability practices and economic performance: Evidence from Italian wine industry. *J. Clean. Prod.* **2018**, *171*, 1300-1311.
25. Mozell, M. R.; Thach, L. The impact of climate change on the global wine industry: Challenges & solutions. *Wine Economics and Policy* **2014**, *3*, 81-89.
26. Jones, G. V.; Alves, F. Impact of climate change on wine production: a global overview and regional assessment in the Douro Valley of Portugal. *International Journal of Global Warming* **2012**, *4*, 383-406.
27. De Steur, H.; Temmerman, H.; Gellynck, X.; Canavari, M. Drivers, adoption, and evaluation of sustainability practices in Italian wine SMEs. *Business Strategy and the Environment* **2020**, *29*, 744-762.
28. Falcó, J. M.; Marco-Lajara, B.; Sánchez-García, E.; Gilinsky Jr, A. In *The Economic, Social, and Environmental Value of the Spanish Wine Industry;* Handbook of Research on Sustainability Challenges in the Wine Industry; IGI Global: 2023; pp 169-193.
29. Tahon, C.; Batt, P. J. An Exploratory Study of the Sustainable Practices Used at Each Level of the Bordeaux Wine Value Chain. *Sustainability* **2021**, *13*, 9760.
30. International Organization for Standardization, (ISO) Introduction to ISO 14001:2015. https://www.iso.org/files/live/sites/isoorg/files/store/en/PUB100371.pdf (accessed 25/12/, 2022).
31. Ardente, F.; Beccali, G.; Cellura, M.; Marvuglia, A. POEMS: A Case Study of an Italian Wine-Producing Firm. *Environmental management (New York)* **2006**, *38*, 350-364.
32. Benni, S.; Torreggiani, D.; Barbaresi, A.; Tassinari, P. Thermal performance assessment for energy-efficient design of farm wineries. *Transactions of the ASABE* **2013**, *56*, 1483-1491.
33. Matos, C.; Pirra, A. Water to wine in wineries in Portugal Douro Region: Comparative study between wineries with different sizes. *Sci. Total Environ.* **2020**, *732*, 139332.
34. Barber, N. "Green" wine packaging: targeting environmental consumers. *International Journal of Wine Business Research* **2010**, *22*, 423-444.
35. Polanco, A. F.; Sandoval, S. M.; Suárez, C. R. In *In The relation between consumer green behavior, sustainable packaging, and brand image in the purchase of ecological wines;* Proceedings of the European Conference on Innovation and Entrepreneurship, ECIE; 2021; , pp 338-346.
36. Schimmenti, E.; Migliore, G.; Di Franco, C. P.; Borsellino, V. Is there sustainable entrepreneurship in the wine industry? Exploring Sicilian wineries participating in the SOStain program. *Wine Economics and Policy* **2016**, *5*, 14-23.
37. Mariani, A.; Vastola, A. Sustainable winegrowing: Current perspectives. *International Journal of Wine Research* **2015**, 37-48.
38. Dodds, R.; Graci, S.; Ko, S.; Walker, L. What drives environmental sustainability in the New Zealand wine industry? An examination of driving factors and practices. *International Journal of Wine Business Research* **2013**, *25*, 164-184.
39. Forbes, S. L.; De Silva, T. Analysis of environmental management systems in New Zealand wineries. *International Journal of Wine Business Research* **2012**, *24*, 98-114.
40. Gilinsky Jr, A.; Newton, S. K.; Vega, R. F. Sustainability in the global wine industry: Concepts and cases. *Agriculture and agricultural science procedia* **2016**, *8*, 37-49.

41. Ozbun, T. Number of wineries in Italy from 2018 to 2021. https://www.statista.com/statistics/786242/number-wineries-italy/#statisticContainer (accessed 14 October, 2023).
42. Italian Wine Central Staff Wine Production by Region . https://italianwinecentral.com/wine-production-in-italy-by-region/ (accessed 14 October, 2023).
43. Sellers, R.; Alampi-Sottini, V. The influence of size on winery performance: Evidence from Italy. *Wine economics and policy* **2016**, *5*, 33-41.
44. Asiamah, N.; Mensah, H. K.; Oteng-Abayie, E. Non-Probabilistic Sampling in Quantitative Clinical Research: A Typology and Highlights for Students and Early Career Researchers. *International Journal of Applied Research on Public Health Management (IJARPHM)* **2022**, *7*, 1-18.
45. Ayhan, H. Ö In *Non-probability Sampling Survey Methods;* International Encyclopedia of Statistical Science; Springer Berlin Heidelberg: Berlin, Heidelberg, 2014; pp 979-982.
46. Vasantha Raju, N.; Harinarayana, N. S. In *In Online survey tools: A case study of Google Forms;* National conference on scientific, computational & information research trends in engineering, GSSS-IETW, Mysore; 2016; .
47. Hui, I. K.; Chan, A. H. S.; Pun, K. F. A study of the Environmental Management System implementation practices. *Journal of Cleaner Production* **2001**, *9*, 269.
48. Zorpas, A. Environmental management systems as sustainable tools in the way of life for the SMEs and VSMEs. *Bioresource technology* **2010**, *101*, 1544-1557.
49. Ikram, M.; Zhang, Q.; Sroufe, R.; Shah, S. Z. A. Towards a sustainable environment: The nexus between ISO 14001, renewable energy consumption, access to electricity, agriculture and CO2 emissions in SAARC countries. *Sustainable production and consumption* **2020**, *22*, 218-230.
50. Massoud, M. A.; Fayad, R.; El-Fadel, M.; Kamleh, R. Drivers, barriers and incentives to implementing environmental management systems in the food industry: A case of Lebanon. *Journal of cleaner production* **2010**, *18*, 200-209.
51. Cordano, M.; Marshall, R. S.; Silverman, M. How Do Small and Medium Enterprises Go Green? A Study of Environmental Management Programs in the U.S. Wine Industry. *J Bus Ethics* **2010**, *92*, 463-478.
52. Bartocci, P.; Fantozzi, P.; Fantozzi, F. Environmental impact of Sagrantino and Grechetto grapes cultivation for wine and vinegar production in central Italy. *Journal of cleaner production* **2017**, *140*, 569-580.
53. Merli, R.; Preziosi, M.; Acampora, A. Sustainability experiences in the wine sector: toward the development of an international indicators system. *Journal of cleaner production* **2018**, *172*, 3791-3805.
54. Abascal, E.; Esteban, I. G. *Análisis de encuestas;* Esic editorial: 2005; .
55. Shortis, T. *The language of ICT: Information and communication technology;* Intertext; Roudlege: USA, 2001; .
56. Evans, D.; Bratton, S.; McKee, J. *Social media marketing;* AG Printing & Publishing: 2021; .
57. Saravanakumar, M.; SuganthaLakshmi, T. Social media marketing. *Life science journal* **2012**, *9*, 4444-4451.
58. Cloquell-Ballester, V.; Monterde-Díaz, R.; Cloquell-Ballester, V.; Torres-Sibille, A. d. C. Environmental education for small- and medium-sized enterprises: Methodology and e-learning experience in the Valencian region. *Journal of environmental management* **2008**, *87*, 507-520.
59. Campos, L. M. S.; de Melo Heizen, Daiane Aparecida; Verdinelli, M. A.; Cauchick Miguel, P. A. Environmental performance indicators: a study on ISO 14001 certified companies. *Journal of cleaner production* **2015**, *99*, 286-296.
60. Nishitani, K. An empirical study of the initial adoption of ISO 14001 in Japanese manufacturing firms. *Ecol. Econ.* **2009**, *68*, 669-679.
61. Martín-de Castro, G.; Amores-Salvadó, J.; Navas-López, J. E. Environmental management systems and firm performance: Improving firm environmental policy through stakeholder engagement. *Corporate social responsibility and Environmental Management* **2016**, *23*, 243-256.

62. Gabzdylova, B.; Raffensperger, J. F.; Castka, P. Sustainability in the New Zealand wine industry: drivers, stakeholders and practices. *J. Clean. Prod.* **2009**, *17*, 992-998.
63. Forbes, S. L.; Cohen, D. A.; Cullen, R.; Wratten, S. D.; Fountain, J. Consumer attitudes regarding environmentally sustainable wine: an exploratory study of the New Zealand marketplace. *J. Clean. Prod.* **2009**, *17*, 1195-1199.
64. Medina, G.; Thomé, K. Transparency in global agribusiness: transforming Brazil's soybean supply chain based on companies' accountability. *Logistics* **2021**, *5*, 58.
65. Rahman, M. M. Environmental degradation: The role of electricity consumption, economic growth and globalisation. *J. Environ. Manage.* **2020**, *253*, 109742.
66. Napa Green Napa Green Program . https://napagreen.org/ (accessed 14/03/, 2024).
67. Galati, A.; Sakka, G.; Crescimanno, M.; Tulone, A.; Fiore, M. What is the role of social media in several overtones of CSR communication? The case of the wine industry in the Southern Italian regions. *Br. Food J.* **2019**, *121*, 856-873.
68. Ugalde, D.; Renaud-Gentié, C.; Symoneaux, R. Perception of French wine buyers regarding environmental issues in wine production. *Journal of Wine Research* **2021**, *32*, 77-102.
69. Kelley, K.; Todd, M.; Hopfer, H.; Centinari, M. Identifying wine consumers interested in environmentally sustainable production practices. *International Journal of Wine Business Research* **2022**, *34*, 86-111.
70. Burawat, P. The relationships among transformational leadership, sustainable leadership, lean manufacturing and sustainability performance in Thai SMEs manufacturing industry. *International Journal of Quality & Reliability Management* **2019**, *36*, 1014-1036.
71. Fragoso, R.; Figueira, J. R. Sustainable supply chain network design: An application to the wine industry in Southern Portugal. *J. Oper. Res. Soc.* **2021**, *72*, 1236-1251.
72. Iannone, R.; Miranda, S.; Riemma, S.; De Marco, I. Improving environmental performances in wine production by a life cycle assessment analysis. *J. Clean. Prod.* **2016**, *111*, 172-180.
73. Zhang, L.; Ye, F.; Yang, L.; Zhou, G. Impact of political connections on corporate environmental performance: From a green development perspective. *Sustainability* **2019**, *11*, 1317.
74. Song, Y.; Yu, H.; Tan, Y.; Lv, W.; Fang, D.; Liu, D. Similarity matching of food safety incidents in China: Aspects of rapid emergency response and food safety. *Food Control* **2020**, *115*, 107275.
75. Giacomarra, M.; Galati, A.; Crescimanno, M.; Tinervia, S. The integration of quality and safety concerns in the wine industry: the role of third-party voluntary certifications. *J. Clean. Prod.* **2016**, *112*, 267-274.
76. Fiore, M.; Giacomarra, M.; Crescimanno, M.; Galati, A. Quality certifications' impact on wine industry assets performance. *Bulgarian Journal of Agricultural Science* **2020**, *26*.
77. Chaudhary, R. Green human resource management and employee green behavior: an empirical analysis. *Corporate Social Responsibility and Environmental Management* **2020**, *27*, 630-641.
78. Saeed, B. B.; Afsar, B.; Hafeez, S.; Khan, I.; Tahir, M.; Afridi, M. A. Promoting employee's proenvironmental behavior through green human resource management practices. *Corporate Social Responsibility and Environmental Management* **2019**, *26*, 424-438.
79. López-Santiago, J.; García, A. I. G.; Gómez-Villarino, M. T. An Evaluation of Food Safety Performance in Wineries. *Foods* **2022**, *11*.
80. Hameed, Z.; Khan, I. U.; Islam, T.; Sheikh, Z.; Naeem, R. M. Do green HRM practices influence employees' environmental performance? *International Journal of Manpower* **2020**, *41*, 1061-1079.
81. Riyanto, S.; Endri, E.; Herlisha, N. Effect of work motivation and job satisfaction on employee performance: Mediating role of employee engagement. *Problems and Perspectives in Management* **2021**, *19*, 162.

4.5 Article four

López-Santiago, J.; Md Som, A.; Asyadi Bin Md Yusof, F.; Mazarrón, F.R.; Gómez-Villarino, M.T. **Exploring Sustainability in Wineries: Evaluating Food Safety and Environmental Management Aligning with the Farm to Fork Strategy.** Agriculture 2024, 14, 330. https://doi.org/10.3390/agriculture14030330. JCR (2022): Q1.

This study successfully addresses the **specific objective (SO-4)** outlined in the thesis, which was to design and evaluate a tool for measuring progress towards sustainability in the wine industry. The outcomes of this study significantly augment the understanding of how to measure the industry's progress towards sustainability.

This is achieved through the comprehensive analysis and evaluation of FS and EM practices in the wine sector. Furthermore, the findings substantiate the central hypothesis of this thesis: the degree to which FSMS and EMS grounded in HACCP and ISO 14001:2015 standards, are implemented in wineries can serve as a quantitative measure for assessing the sustainability paradigm.

The outcomes establish the SM based on FS and EM. The construction of this matrix, which assesses the extent of progress toward sustainability in wineries, involves the results of all indicators derived from the results of the FS performance indicators obtained from the analysis of case study two and the results of the EM performance indicators from case study three. Utilizing a color-coded reading method, the matrix is devised wherein each indicator value is depicted by a green line. The gradations denoting progress toward sustainability are delineated as follows: 'Star' for indicator values ranging from 0 to 0.33, 'In progress' for values between 0.34 and 0.67, and 'Maturity' for values spanning 0.68 to 1.

The **Table 8** corresponds to the SM, based on the performance of the FSMS which was obtained through the arithmetic mean of the wineries sample analysed in case study two, and the EMS performance derived from the arithmetic mean of the wineries sample analysed in case study three.

Table 8. Sustainability Matrix based on the performance of the FSMS and EMS

Sustainability Matrix (SM)					
Components	Performance Indicator	Value	Grade of Progress		
			Start	In progress	Maturity
Food Safety Management					
FS training	W_{fswt}	0.86			
Legal requirements	W_{liu}	0.43			
Analysis	$W_{ccp-Mchem}$	0.32			
Environmental Management					
Communication	W_{ecm}	0.34			
Commitment	W_{ecx}	0.64			
Planning	W_{epx}	0.55			
Other Env. Requirements	W_{erx}	0.51			
Environmental Training	W_{ewt}	0.66			

The SM functions as an instrumental tool that explores RQs regarding the critical factors and essential performance indicators that accurately gauge the sustainability achievements of wineries. This exploration is focused through the lenses of FS and EM practices. Additionally, the SM examines the roles that FS and EM play in developing a comprehensive tool that could serve as a comprehensive measure of a winery sustainability journey, encapsulating the full spectrum of sustainable practices within the industry.

agriculture

Article

Exploring Sustainability in Wineries: Evaluating Food Safety and Environmental Management Aligning with the Farm to Fork Strategy

Jesús López-Santiago [1,*], Amelia Md Som [2], Fahmi Asyadi Bin Md Yusof [2], Fernando R. Mazarrón [1] and María Teresa Gómez-Villarino [1]

[1] School of Agricultural, Food and Biosystems Engineering, Universidad Politécnica de Madrid, 28040 Madrid, Spain; f.ruiz@upm.es (F.R.M.); teresa.gomez.villarino@upm.es (M.T.G.-V.)
[2] Malaysian Institute of Chemical & Bioengineering Technology (UniKL MICET), Universiti of Kuala Lumpur, Kuala Lumpur 50250, Malaysia; ameliamds@unikl.edu.my (A.M.S.); fahmiasyadi@unikl.edu.my (F.A.B.M.Y.)
* Correspondence: jesus.lopez.santiago@upm.es

Abstract: The Farm to Fork (F2F) Strategy, a key initiative of the European Commission under the European Green Deal, strives to make the European Union's (EU) economy sustainable. Focused on the food system, the F2F Strategy prioritizes sustainability in agriculture, eco-friendly practices, biodiversity preservation, and climate change mitigation. It targets high food safety (FS) and environmental management (EM) standards across the Agri-food Supply Chain (ASC). Addressing sustainability challenges in the wine industry, this study delves into the Wine Value Chain (WVC). Emphasizing the intricate sustainability interplay within the WVC, this study concentrates on FS and EM to ensure the long-term viability of wine production. The primary goal is to create a comprehensive sustainability evaluation method for wineries, incorporating performance indicators from FS and EM components. The methodology involves assessing Food Safety Management Systems (FSMSs), evaluating Environmental Management Systems (EMSs), investigating contamination risks, and synthesizing results into a sustainability matrix. Findings highlight commendable FS practices, such as widespread Hazard Analysis and Critical Control Point (HACCP) adoption and underscore the need for increased EM focus. Notable figures include a 76.2% adoption of the HACCP system and 68.8% of wineries implementing an EMS. Performance indicators become critical for sustainability assessment, forming the cornerstone to gauge the industry's effective sustainability management aligned with the F2F Strategy. This study stresses the holistic integration of FS and EM practices, providing insights into workforce engagement, regulatory compliance, and sustainable objectives. This research offers a tool for evaluating and advancing sustainability in the wine industry culminating in a sustainability matrix.

Keywords: sustainable wine production; food safety management; environment management; wine; beverages

Citation: López-Santiago, J.; Md Som, A.; Asyadi Bin Md Yusof, F.; Mazarrón, F.R.; Gómez-Villarino, M.T. Exploring Sustainability in Wineries: Evaluating Food Safety and Environmental Management Aligning with the Farm to Fork Strategy. *Agriculture* **2024**, *14*, 330. https://doi.org/10.3390/agriculture14030330

Academic Editors: Giuseppa Di Bella, Vincenzo Nava and Ambrogina Albergamo

Received: 14 January 2024
Revised: 14 February 2024
Accepted: 16 February 2024
Published: 20 February 2024

1. Introduction

The F2F Strategy is an initiative introduced by the European Commission [1,2]. It is part of the European Green Deal, which is a set of policy initiatives by the EU aimed at making the EU's economy sustainable [3]. The F2F Strategy specifically focuses on the food system, aiming to make it more sustainable, resilient, and environmentally friendly. The F2F Strategy prioritizes sustainability in agriculture, emphasizing environmentally conscious practices, biodiversity preservation, and climate change mitigation. It also aims to ensure high FS standards across the food supply chain, reduce the use of chemical pesticides and fertilizers, promote the transition to organic farming, and encourage a circular economy in the food sector, thereby minimizing waste and optimizing resource utilization [4,5]. Challenges faced by the food industry in terms of sustainability are vast, covering environmental, social, and economic dimensions that impact every stage of food production, distribution, and consumption [6,7]. Addressing these complexities requires the implementation of sustainable practices that align with economic feasibility, social justice, and environmental preservation [8–10]. Despite some initial efforts, the food industry is still in the initial stages of adopting sustainability practices. Numerous studies have highlighted the challenges and opportunities faced by agri-food firms in relation to sustainability [11–13]. However, given the increasing complexity of this sector, there is an urgent need to develop more structured methodologies that systematically incorporate sustainability considerations [14].

Sustainability, broadly defined, focuses on enhancing people's quality of life by considering social, economic, and environmental perspectives and ensuring this improvement for future generations [15,16]. The concept of sustainability arises from the four dimensions within the ASC performance [17]. The ASC covers all activities related to agricultural food handling, from producers and farmers to end consumers [18]. Aramyan et al. (2007) identify four primary performance dimensions: efficiency, flexibility, responsiveness, and food quality [17]. Moreover, an additional category is introduced to address critical aspects reflecting the social and environmental dimensions of sustainability [19]. Refining the sustainability dimension, Gold (2017) outlines indicators such as local living conditions, labor rights, land rights, end-of-life valorization through biomass recycling, environmental issues, and FS [12]. Consequently, agri-food industries allocate a substantial portion of their resources toward advertising and marketing initiatives focused on sustainability [20,21]. The ASC consumes natural resources and often causes environmental deterioration of the natural ecosystems where it develops. From this point of view, FS and EM play an important role in the sustainability of the environment where agro-industrial activity takes place [22]. According to Kumar (2022), FS and EM topics such as waste management or environmental impact assessments are two of nine key thematic research themes in sustainable food supply chains [23]. Figure 1 displays an interpretative diagram that, from a scientific perspective, grounds the reason why the evaluations of FS along with EM stand as quantitative pillars in achieving sustainability within the ASC.

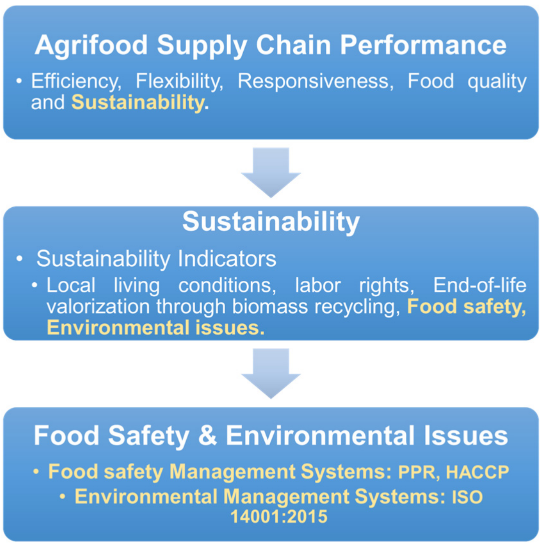

Figure 1. Diagram showing FS and EM as quantitative pillars contributing to sustainability in the ASC.

The WVC constitutes an integral component of ASC insofar as it encompasses the production, processing, distribution, and sale of agricultural products, in this instance, wine. WVC encompasses the full range of activities and processes required to bring wine from vineyard to consumer, including grape cultivation, wine production, bottling, distribution, marketing, and sales. It involves a complex network of stakeholders including grape growers, winemakers, bottlers, distributors, retailers, and consumers [24]. WVC is characterized by its emphasis on quality, tradition, and sustainability, reflecting the unique terroir of wine-producing regions, as well as the cultural and historical significance of wine [25].

Prior research underscores this multifaceted nature of sustainability in the wine sector, advocating for a comprehensive approach that balances environmental integrity with economic viability, social equity, and cultural heritage. Szolnoki (2013) underscores the diversity in sustainability practices across WVC in various wine-producing nations, highlighting the need for a holistic approach that integrates local and global sustainability standards [26]. Forbes et al. (2009) explore consumer attitudes towards environmentally sustainable wine in New Zealand, revealing a growing consumer demand for sustainability in the wine industry, which influences market dynamics and winery practices, and Pickering G. (2023) found that most consumers are in a change stage with respect to sustainable wine behaviors [27]. This consumer-driven shift towards sustainability is further corroborated by Gabzdylova et al. (2009), who examine the drivers, stakeholders, and sustainability practices within the New Zealand WVC, suggesting that stakeholder engagement and transparent sustainability reporting are key to advancing sustainable practices [28]. Marshall et al. (2005) investigate the institutional and individual drivers of environmentalism in the US wine industry, emphasizing the role of proactive environmental strategies in gaining competitive advantage and meeting regulatory and societal expectations [29]. De Steur et al. (2020) identified the role of drivers in the adoption of sustainability in Italian wineries, with internal drivers such as the protection of regional products and environmental benefits (e.g., biodiversity or landscape protection) being deemed highly important, as well as some external drivers related to environmental and product safety [30]. Santini et al. (2013) address the critical questions and research trends in wine industry sustainability, calling for a comprehensive understanding and integration of sustainable practices that encompass the entire WVC [25].

In this context, sustainability in WVC has grown in recent years, reflecting an increasing interest in environmentally friendly agricultural and viticultural practices. Sustainability, in this context, pertains to the ability to maintain wine production in the long term without compromising natural resources or harming the environmental context. Meissenheimer et al. (2001) identified specific categories within the WVC, covering a range of activities. These activities involve managing soil and plant materials, implementing vineyard practices, conducting cellar practices and wine production, handling packaging and distribution, and engaging in market development and marketing [31]. WVCs encounter challenges across three primary areas: global and environmental challenges, methodological and financial challenges, and challenges associated with the economy and the market [32]. According to Luzzani (2021), sustainability in the wine industry incorporates various aspects, including field operations, grape transformation, and the cultural and traditional heritage of wine [33]. Sustainable vitiviniculture involves a global strategy that considers economic sustainability, precision in sustainable viticulture, risks to the environment, product safety, and consumer health, along with the valuation of heritage, historical, cultural, ecological, and landscape aspects as emphasized by the Organisation Internationale de la Vigne et du Vin (OIV) (2008) [34]. This underscores the need for a comprehensive approach that includes both FS and EM in all stages of the production process.

FS refers to the assurance and set of conditions and measures needed during the production, storage, distribution, and preparation of food to ensure that, when consumed, they do not pose a risk to the health of consumers [35]. FS plays a critical role in the sustainability of wine production. FSMSs are essential for ensuring the production of safe and healthy food, incorporating prerequisite programs (PRPs) and HACCP methodologies as per the regulatory standards in the EU [36,37]. PRPs establish the necessary environmental and operational conditions, covering aspects such as the supply of sanitary water, cleanliness of equipment and facilities, pest control, good manufacturing practices, staff knowledge of FS, allergens, and food traceability [38]. HACCP is a globally recognized approach focused on identifying and controlling FS hazards through seven principles, which include hazard identification, determining Critical Control Points (CCPs), and setting critical limits for these CCPs [39]. CCPs are specific points in the food production process where controls are essential to prevent, eliminate, or reduce FS hazards to acceptable levels. The identification and management of CCPs involve a systematic analysis, employing decision tree frameworks aligned with Codex Alimentarius and ISO 22000:2018 criteria, to decide on the appropriate controls and preventive measures [40,41]. Effective management of CCPs in wine production, through regular monitoring, verification, and documentation, is critical to maintaining FS and preventing contamination [42].

EM is essential for ensuring the long-term sustainability of wine production. Environmental considerations, such as waste reduction and recycling, efficient use of raw materials, and resource conservation, enable wineries to build trust with stakeholders and gain competitive advantages [43]. According to Gilinski et al., the focus for practitioners in the wine industry is to leave the land in better conditions than the current ones for future generations, addressing EM and incorporating strategies that minimize the negative impact of viticulture on the natural environment [44]. An EMS encompasses a set of practices, guidelines, and records established by an organization to reduce the environmental footprint of its operations [45]. EMSs are adopted by numerous organizations globally [46,47] and often align with ISO 14001:2015 standards [48], serving as a framework for active environmental stewardship [49,50]. The ISO 14001:2015 standard outlines essential criteria that all EMSs should adhere to, emphasizing ongoing, methodical enhancement. Organizations utilize this standard to boost their environmental outcomes, aligning with their environmental commitments, goals, and duties, thereby contributing to the environmental dimension of sustainability [51]. Typically, the adoption of an EMS is driven by the ethical and competitive aspirations of the organization's leadership [52].

By incorporating both FS systems and EM in wine production, producers contribute to the sustainability of the wine industry. Baiano, A. (2021) suggests that implementing sustainable practices helps reduce the environmental footprint of wine production and promotes the conservation of natural resources [53]. Furthermore, these practices can enhance consumer credibility and perception. From the consumer perspective, sustainability is primarily associated with credibility attributes inherent to the food they consume [54].

Within this framework, the primary objective of this research is to develop a method for evaluating the advancement in the concept of sustainability in wineries. This is based on their performance in FSMSs and EMSs, measured through the creation of performance indicators derived from components of FS and EM.

2. Materials and Methods

This research initiated an extensive data collection effort, focusing on three samples of wineries situated in diverse geographic locations, covering a range of operational scales. Each group comprised over thirty wineries, enabling the application of the Central Limit Theorem (CLT) [55,56]. The CLT is a cornerstone principle in statistics that supports the use of samples of thirty or more to make inferences about a broader population. This includes the context of categorical variables, particularly when evaluating proportions or percentages. The data, meticulously collected via surveys, provide a comprehensive overview of current practices in FS and EM within the wine industry. This contextual foundation is pivotal for interpreting the results, offering a perspective through which the sustainability initiatives of wineries can be evaluated against global sustainability standards.

The methodological approach was structured in four well-defined steps. The first three steps were dedicated to analyzing different case studies. The first step laid the groundwork for defining the objectives of the second case, which focused on FS, while the results of the second supported the methodology to develop the indicators in the third study, which focused on EM. In each of these stages, the efficacy with which the wineries implemented the FSMS or the EMS was meticulously evaluated. The four steps involved synthesizing the three investigations to develop an FS and EM sustainability matrix based on performance indicators calculated from the results of case studies two and three. Through detailed statistical analysis and the examination of these cases, the research offers a deep dive into the sustainability practices within the wine sector based on FS and EM. Figure 2 shows the evolution of this methodological approach, inclusive of the interconnections among the steps and their congruence with the theoretical framework. The outcomes of the first case study facilitated the identification of CCPs that were inadequately managed by the wineries and the principal components that support the wineries' performance in FS management. Leveraging these findings, the second case study delineated performance indicators for the components identified in the first phase. The third case study delved into the EM practices by examining the EMS components based on the ISO 14001:2015 standard and employed the proposed methodology to compute the indicators from the second phase to formulate performance indicators in EM. The fourth step focused on combining the findings from the three previous investigations to create a sustainability matrix based on FS and EM.

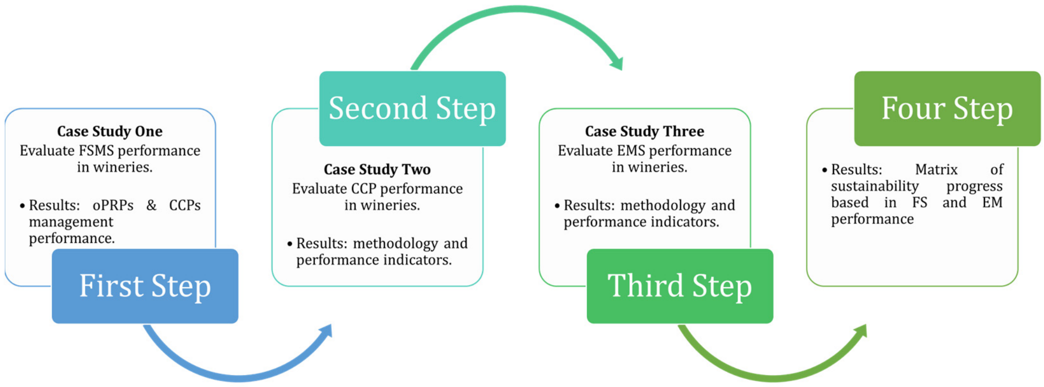

Figure 2. Flow diagram of the methodological process.

2.1. First Step

In the initial phase, a first case study was conducted to evaluate the effectiveness of the FSMS based on PRPs and the HACCP in twenty-one wineries with the Protected Designation of Origin "Vinos de Madrid". The performance of these wineries was thoroughly assessed at various stages of the wine production process, focusing on Critical Control Points (CCPs) or operational prerequisite programs (oPRPs), including the implementation of PRPs and adherence to HACCP principles [39]. This research utilized a structured survey with fifty-five questions grouped into eleven sections. The questions employed both yes/no and multiple-choice options, with quantitative variables assigned using Likert scales. Figure 3 illustrates the questionnaire structure, detailing questions and assigned variables for the statistical process. The questionnaire is included in Appendix A.

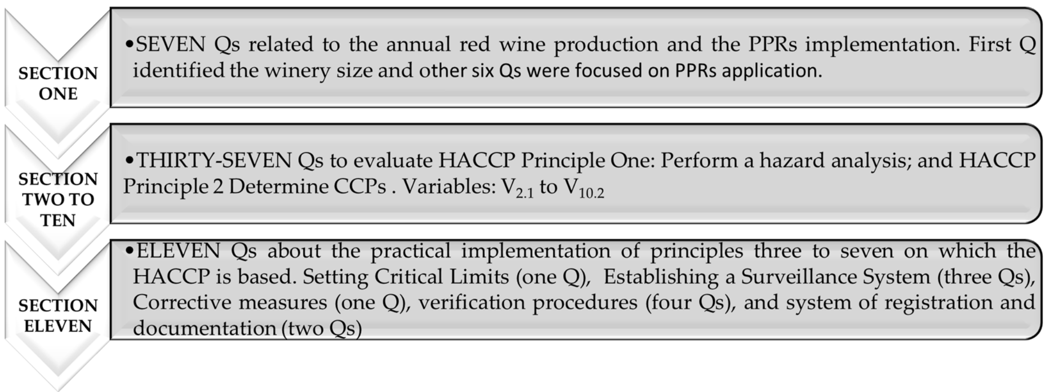

Figure 3. Questionnaire structure, including questions and variables for case study one.

2.2. Second Step

According to the findings of Lopez Santiago et al. (2022), the second case study focused on a CCP identified as inadequately controlled, specifically addressing the risk of contamination from arsenic, cadmium, and lead during the wine production process [57]. A sixteen-question survey assessed wineries' performance in various aspects, including training workers, monitoring CCPs, understanding relevant legislation on contamination risks, and evaluating wineries' practices regarding the chemical analysis of vineyard soils.

The questionnaire, distributed to thirty-two wineries across different Protected Designations of Origin in Spain, incorporated both yes/no and multiple-choice questions, with quantitative variables assigned using Likert scales. Figure 4 outlines the questionnaire structure. The questionnaire is included in Appendix A.

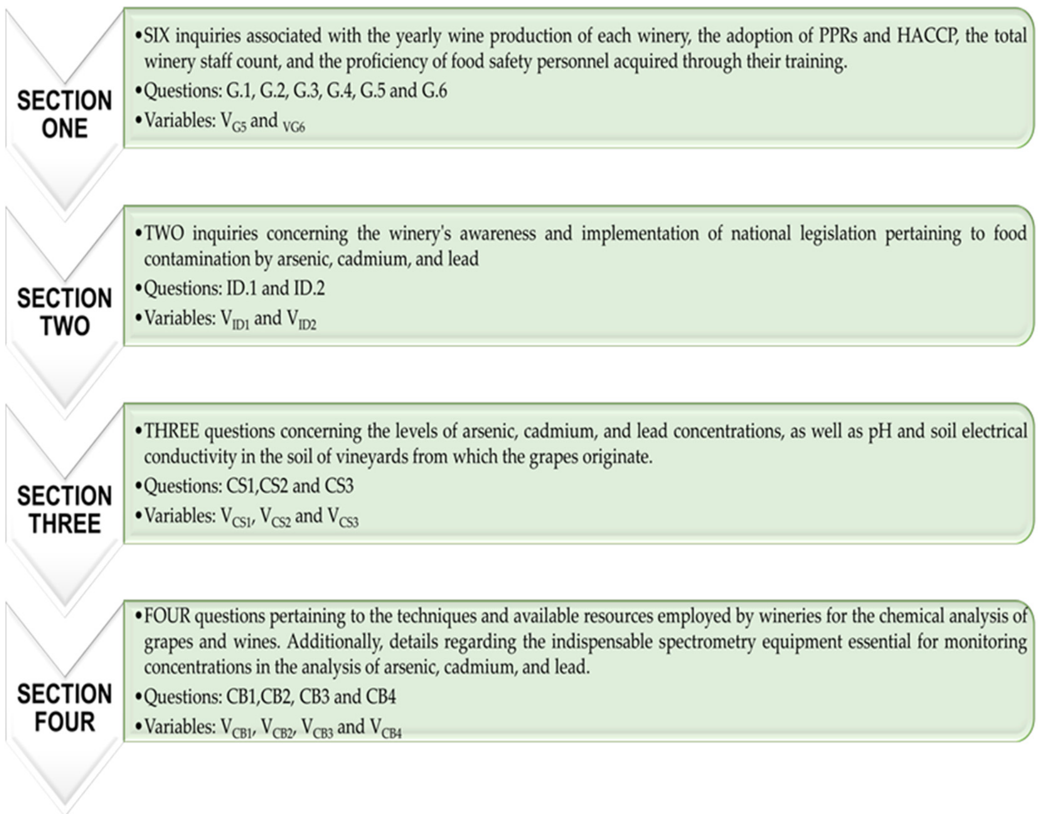

Figure 4. Questionnaire structure, including questions and variables for case study two.

2.3. Third Step

A third case study extended its scope to Italian wineries, focusing on their EMS. Conducted between June and November 2022, the survey involved a sample of 120 wineries from various regions in Italy, with the subsequent data analysis using statistical tools such as SPSS and Excel. The comprehensive questionnaire, featuring thirty-two questions in closed and open-ended formats, Likert scales, and multiple-choice options, explored aspects like winery characteristics, environmental objectives, top management involvement, communication strategies, and emergency plans. The questionnaire was distributed to a non-probabilistic sample of Italian wineries, resulting in responses from thirty-four wineries. Figure 5 provides an overview of the questionnaire structure, including questions and variables. The questionnaire is included in Appendix A.

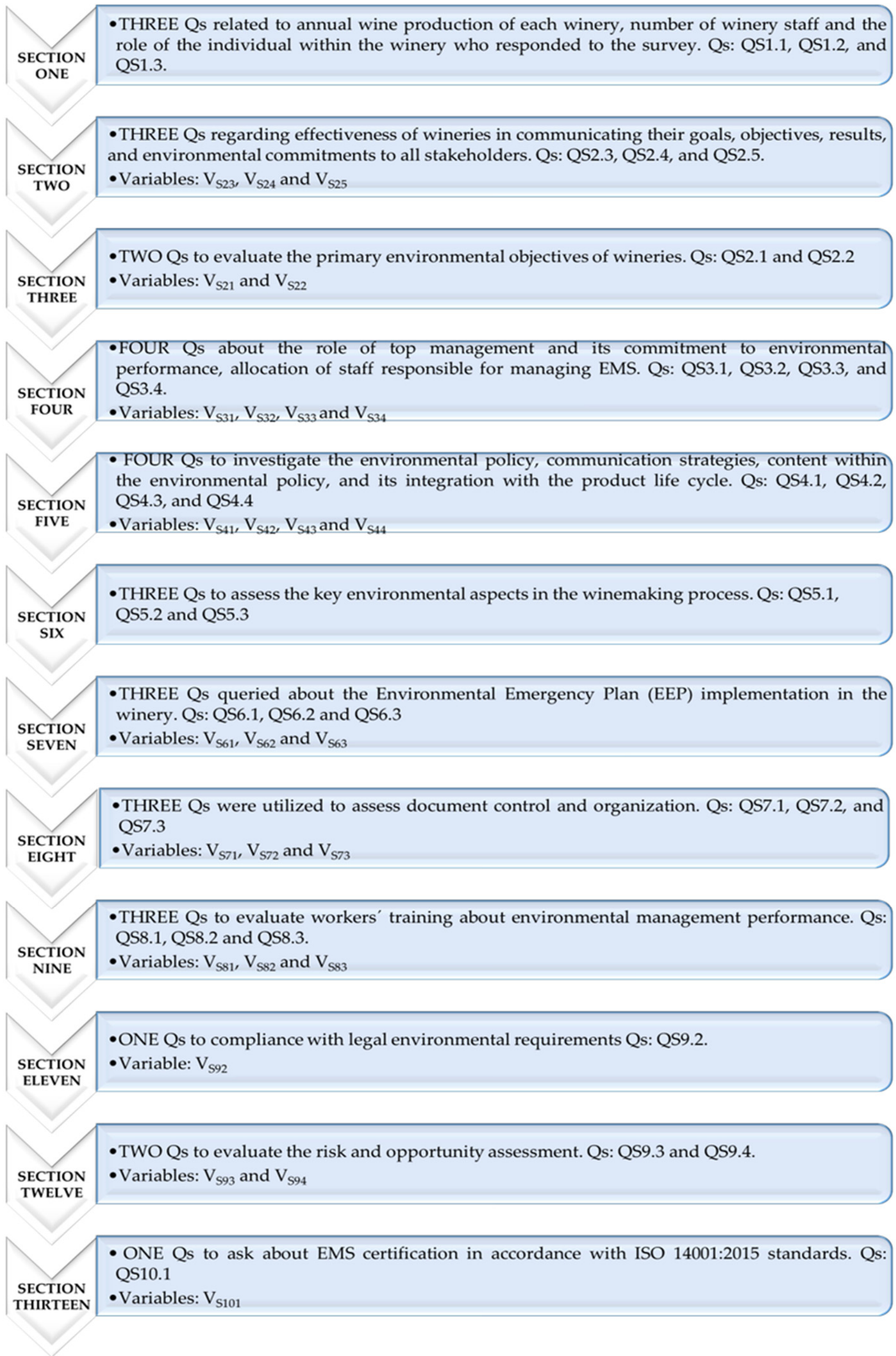

Figure 5. Questionnaire structure, including questions and variables for case study three.

2.4. Four Step

The fourth phase involved the three case studies that were utilized to create an FS and EM sustainability matrix using the performance indicators derived from the findings of the second and third case studies analyzed.

The three research case studies employed rigorous statistical methods, including frequencies, central position values, cross-tables, and specific nonparametric tests such as the Spearman correlation coefficient, Kendall's Tau coefficient, and the Mann–Whitney U Test, all conducted at a predetermined significance level.

3. Results

3.1. FS Management Performance

The first case study provides a detailed look at FS in wineries, highlighting the complex nature of FSM practices, with a particular focus on the implementation of PRPs and the HACCP system. This scrutiny unravels the pivotal role of annual wine production levels, with wineries classified into distinct groups based on their production volumes, allowing for a nuanced exploration of correlations with workforce training, economic considerations, and the overall efficacy of HACCP control performance.

Within the confines of PRP implementation, the study discloses a commendable 91.5% success rate, delineating the percentage of wineries that have seamlessly integrated specific programs within the standard PRPs. An intricate analysis of FS worker training unfolds, indicating that 81% of wineries possess a workforce where at least 50% are trained in Good Manufacturing Practices in winemaking, with a discernible concentration in wineries surpassing an annual wine production of 100,000 L/year. Notably, the economic dimension is explored, revealing that 62% of wineries formulate their PRP plans without a specific annual budget, accentuating a substantive correlation between winery size and the presence of a dedicated budget for PRP development.

An exploration of HACCP implementation in wineries ensues, encompassing the overall implementation rate, performance in principles one and two, and a meticulous examination of specific control points. The study discloses a commendable 76.2% embrace of HACCP, showcasing variations contingent on annual production levels. The identified CCPs and oPRPs are thoughtfully categorized based on median values and variability, offering insights into the extent of control over each CCP. This in-depth analysis underscores the essential role of well-controlled CCPs in ensuring the safety of the final wine product.

Table 1 illustrates the control performance of CCPs and oPRPs in the red wine process through the application of a color-coded reading method, where cells were color-coded ranging from dark orange (lowest control) to dark blue (highest control).

Table 1. Control performance of CCPs and oPRPs in the red wine process by wineries.

Winemaking Steps	CCPs & oPRPs	Always (3)	Usually (2)	Hardly Ever (1)	Never (0)
1. Harvest and grape transportation	oPRP 2.1 Vineyard inspection prior to the harvest to know the general condition of the grapes.				
	oPRP 2.2 Vineyard inspection during the harvest to know the state of grapes.				
	oPRP 2.3 Control of the time it takes to transport the harvest to the winery.				
2. Harvest reception in the winery	oPRP 3.1 Control of residues of fungicides and/or pesticides existing in grapes intended for winemaking.				
	oPRP 3.2 Mycotoxin control from grape rot.				
	oPRP 3.3 Control of the presence of contamination by plant debris, dust, and/or metallic elements.				
	CCP 3.1 Control of the presence of contamination by metals (Cd, Pb, As) in the grapes.				
3. Pre-hatching treatments	oPRP 4.1 Control of the cleanliness of the tanks to eliminate residues of microorganisms.				
	oPRP 4.2 Control of the absence of cleaning and disinfection products in the tanks.				

Table 1. *Cont.*

Winemaking Steps	CCPs & oPRPs	Always (3)	Usually (2)	Hardly Ever (1)	Never (0)
4. Grapes crushing and must pumping	oPRP 5.1 Control of the cleanliness of crushing equipment.	■			
	oPRP 5.2 Control of the absence of cleaning and disinfection products in tanks and press and pumping equipment.	■			
	CCP 5.1 Control of the must maintenance time in the crusher.				■
5. Sulphited and vatted	oPRP 6.2 Control of the absence of microorganisms in the equipment and tanks.	■			
	CCP 6.1 Control of the safety and purity of additives		■		
6. Alcoholic fermentation, maceration, vat emptying, pressing, malolactic fermentation	oPRP 7.1 Control of the concentration of ethylocarbamate in fermented must.		■		
	oPRP 7.2 Control of hygiene during racking and pressing operations.	■			
	oPRP 7.3 Control of the cleanliness of pressing equipment.	■			
	CCP 7.1 Control of sulphur dioxide in fermented must.	■			
	CCP 7.2 Control of the purity and safety of yeasts.	■			
	CCP 7.3 Temperature control during fermentation.	■			
	CCP 7.4 Control of the pH of red wine during malolactic fermentation.	■			
7.Racking, clarification, and filtration	oPRP 8.1 Control of the cleaning procedures of tanks and transfer equipment.	■			
	oPRP 8.2 Control of maintenance and cleaning procedures of the facilities.	■			
	oPRP 8.3 Control of hygiene operations during clarification and filtering operations.	■			
	oPRP 8.4 Control of the absence of cleaning and disinfection products in tanks and equipment.	■			
	oPRP 8.5 Control of the absence of foreign elements from the filters in red wine.	■			
	CCP 8.1 Control of the purity and safety of agents used as clarifiers in red wine.	■			
	CCP 8.2 Control of the absence of residues of agents used as clarifiers in red wine.		■		
8. Cold stabilization	CCP 9.1 Control of limit concentrations of metals (traces of As, Cu, Pb) in red wine.			■	
	CCP 9.2 Control that the additives used are those allowed by current food legislation.	■			
9. Bottling and labelling	oPRP 10.1 Control of bottle cleaning procedures.		■		
	oPRP 10.2 Control of maintenance and cleaning procedures of the red wine bottling line.	■			
	oPRP 10.3 Control of the correct coding of the labels used on the bottles.	■			
	oPRP 10.4 Control of correct allergen information on labels used on bottles.	■			
	CCP 10.1 Microbiological control of the bottling line of red wine and bottles.			■	
	CCP 10.2 Microbiological control of the cork stopper or similar used for closing the bottles.	■			
	oPRP 2.1 Vineyards inspection prior to the harvest to know the general condition of the grapes.	■			

(0) Dark orange: Group I, (1) Light orange: Group II, (2) Light blue: Group III, (3) Dark blue: Group V/Group IV.

This contingency table was constructed utilizing the medians of categorical variables associated with each analyzed CCP. The categorization into five groups was based on the median values of each variable and the presence of significant variability, as measured by the interquartile range. Group I and Group II denote the CCPs and oPRPs with the least effective control in wineries, thereby presenting a heightened risk to the safety of the final product. Conversely, Group III and Group IV signify the CCPs and oPRPs that exhibit effective control in at least fifty percent of wineries. Group V comprises variables with a median value of three, indicating that the associated CCPs and oPRPs were consistently controlled under the category of "Always".

Moreover, the performance analysis of CCPs highlights varying degrees of control over specific winemaking steps. Correlations between different CCPs are meticulously explored, revealing associations between safety and purity control of additives, residue control from wine clarifiers, and other key variables.

The comprehensive nature of the study delivers a detailed and nuanced analysis of HACCP implementation and control performance, shedding light on specific critical points that necessitate heightened attention to guarantee the safety and quality of the final wine product.

3.2. CCP Control Performance

Wineries' distribution by production capacity in the second case study is displayed in Figure 6.

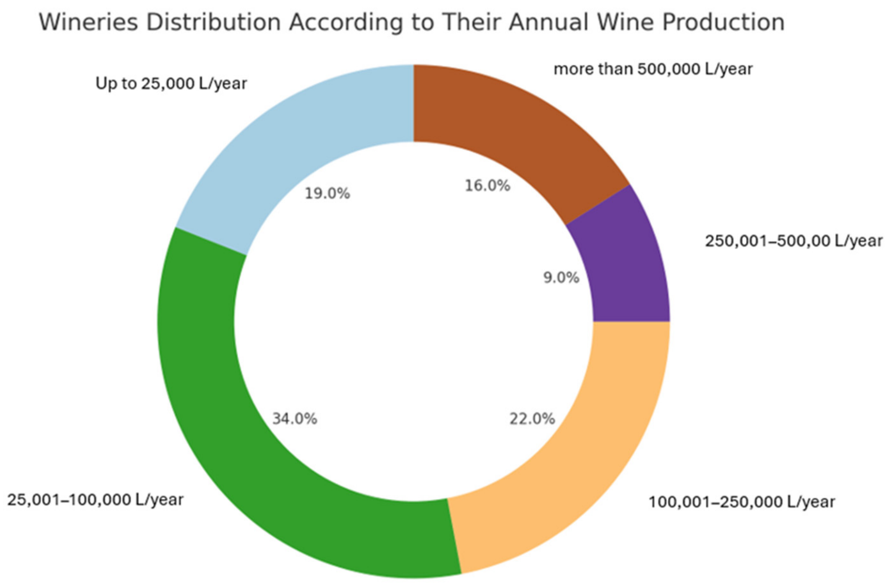

Figure 6. Wineries' distribution by wine annual production capacity.

Study results show how wineries navigate the realms of worker training, legal compliance, and the monitoring of harmful substances like arsenic, cadmium, and lead in grapes and wines. An essential revelation from this exploration is the earnest commitment of most surveyed wineries to FS, with an impressive 96.9% adhering to regulations and 93.8% following industry standards.

The results of Table 2 show that as the winery gets bigger according to its yearly wine production, it has more workers trained in GMPs and CCPs. However, the percentage of trained workers is also high in smaller wineries. This is due to the number of workers ranging between two and three in this winery group, and, therefore, having trained a worker already reaches values of fifty percent.

The correlation between winery size and the number of workers trained in both GMPs and CCPs underscores the industry's recognition of the resource-intensive nature of such training efforts. Notably, there is a positive connection between GMPs and CCP training surfaces, revealing a systematic approach to ensuring FS. Smaller wineries, while exhibiting a high percentage of trained workers, may face limitations in absolute numbers due to their smaller workforce.

Table 2. GMP workers training and CCPs workers training by type of winery.

Wine Annual Production L/Year	Percentage of Wineries Over Total	GMP Workers Training (%)			CCPs Workers Training (%)			Number of Workers	
		All	More Than 50%	None	All	More Than 50%	None	Median	Arithmetic Mean
up to 25,000	18.8	66.7	33.3	0.0	66.7	33.3	0.0	2.5	2.3
25,001–100,000	34.4	60.0	20.0	20.0	40.0	50.0	10,0	4.0	3.3
100,001–250,000	21.9	28.6	57.1	14.3	28.6	57.1	14.3	5.0	5.1
250,001–500,000	9.4	100.0	0.0	0.0	66.7	33.3	0.0	7.0	7.3
more than 500,000	15.6	100.0	0.0	0.0	100.0	0.0	0.0	10.0	21.7
Total wineries Percentage	100.0	65.6	21.9	12.5	53.1	37.5	9.4	4.0	6.1

This investigation delves into legislative compliance and Heavy Metal Food Contamination Risk (HMFCR) laws, revealing suboptimal awareness among smaller wineries regarding critical regulations. The study underlines the industry-wide gap in utilizing available resources, such as information from the National Agency (AESAN), for regulatory compliance. Information from the AESAN is utilized by merely one-third of small to medium-sized wineries, those producing up to 250,000 L per year. In contrast, larger wineries, with production exceeding 250,001 L annually, show a higher usage rate at 66.7%, though this still falls short of being adequate. Additionally, there is a notable lack of clear recognition of HMFCR regulations within wineries, particularly among those with an annual production of less than 250,001 L of wine. Table 3 shows HMFCR legislation identification and HMFCR legislation updating through the AESAN by winery production capacity.

Table 3. HMFCR legislation identification and HMFCR legislation updating through the AESAN by production capacity.

Wine Annual Production L/Year	Percentage of Wineries Over Total	HMFCR Legislation Identification (%)				HMFCR Legislation Updating through AESAN (%)	
		As	Cd	Pb	None	Yes	No
up to 25,000	18.8	33.3	33.3	50.0	50.0	50.0	50.0
25,001–100,000	34.4	33.3	33.3	33.3	66.7	33.3	66.7
100,001–250,000	21.9	28.6	28.6	28.6	71.4	28.6	71.4
250,001–500,000	9.4	66.7	66.7	66.7	33.3	66.7	33.3
more than 500,000	15.6	66.7	66.7	66.7	33.3	66.7	33.3
Total wineries Percentage	100.0	31.2	31.2	37.5	62.5	37.5	62.5

A significant number of wineries maintain records on both the physical and chemical properties of their vineyard soils, alongside data on the fertilizers applied to these soils. There exists a positive tendency among wineries to keep concurrent records of soil composition and the fertilizers applied, indicating that those with comprehensive soil analyses are likely to also possess detailed information on fertilization practices. Figure 7 reflects the proportion of wineries with data about the chemical composition of their vineyard soils.

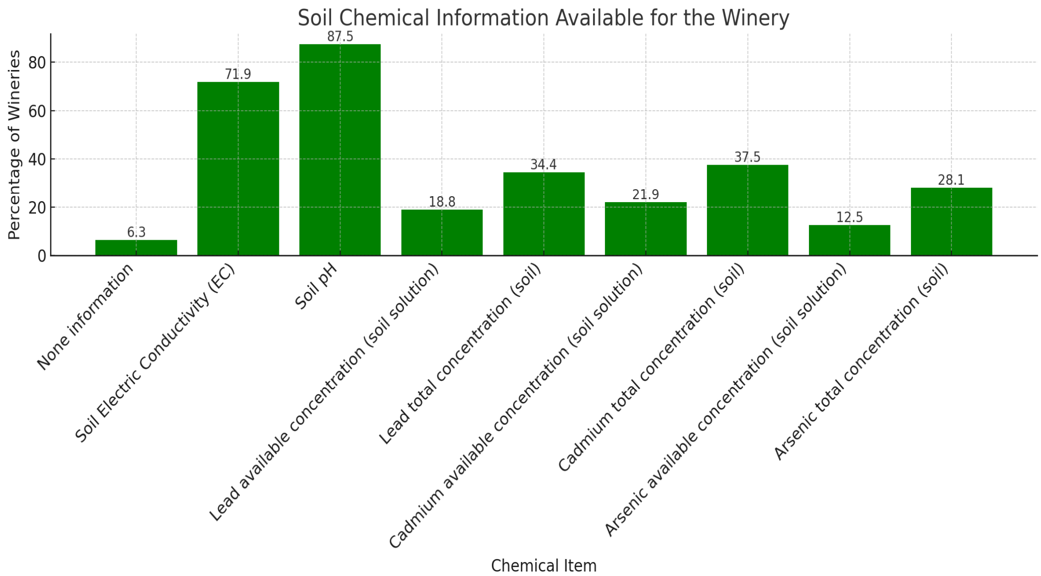

Figure 7. Percentage of wineries with information about each chemical soil item.

A third of wineries have data on soil levels of arsenic, cadmium, and lead, but fewer have information on these elements in soil solutions. Only 10% of wineries have arsenic data, and 20% have cadmium and lead data for vineyard soils. Larger wineries are more likely to have data on total cadmium and lead concentrations, but data on arsenic are rare across all winery sizes. The most reported data is on cadmium in soil solutions, especially among mid-sized wineries. The lack of comprehensive soil contamination data hampers effective risk assessment for grape contamination. Despite this, 78.1% of wineries have their own labs for grape and wine chemical analyses, while 20% rely on external services for such analyses. However, a notable gap emerges concerning information on harmful substances like arsenic, cadmium, and lead, particularly in smaller wineries. This informational void poses a significant challenge in assessing and mitigating contamination risks during winemaking, potentially impacting the final product's quality and safety. While larger wineries generally perform better, differences persist across winery sizes, emphasizing the necessity for targeted interventions that recognize the unique challenges faced by wineries of varying scales.

3.3. EM Performance

The third case study investigates key areas of EM that wineries claim to consider, including communication, commitment, leadership, environmental planning, and training. Initially, it explores the operational dimensions of the wineries, with a focus on both the annual production capacity and the workforce size.

Figure 8 illustrates the wineries' distribution by production capacity, segmented by the number of workers, providing a layered perspective on the operational characteristics of the wineries involved in our survey. This visualization highlights the variance in production capacities, from less than 50,001 L per year to more than 500,000 L per year, and elucidates the corresponding workforce sizes, revealing the diverse approaches to production and manpower management across the sector.

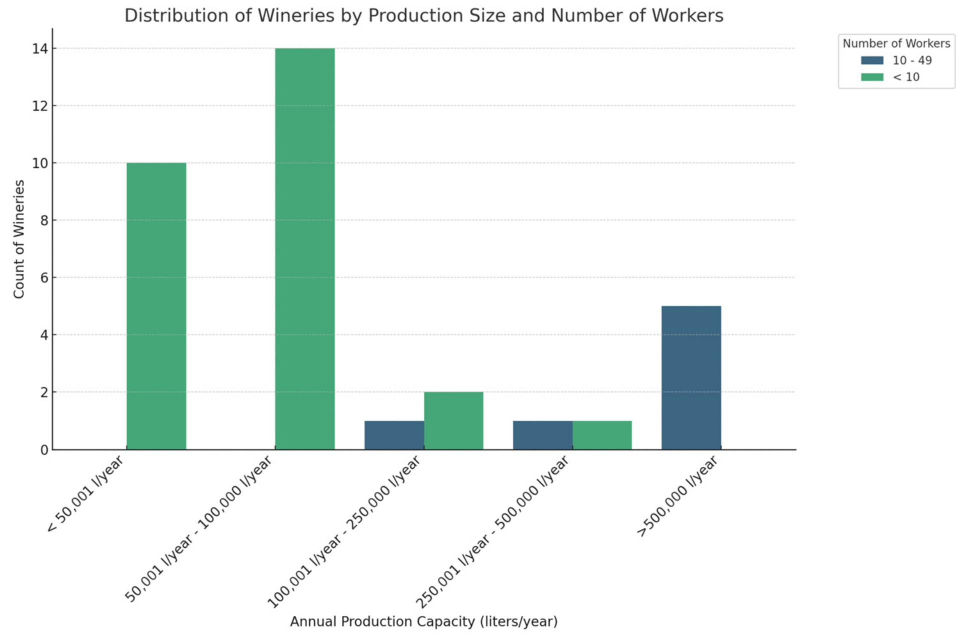

Figure 8. Relationship between production capacity and workforce size.

These insights are instrumental in understanding the scalability and adaptability of EM strategies within the wineries, underlining the critical role of operational scale in sustainable practices. Results highlight a conspicuous lack of clearly defined EM areas in Italian wineries, with only large wineries (80%) having implemented a structured focus on EM.

While the overarching results of our study highlight a pervasive ambiguity in the explicitly defined areas of EM across the surveyed wineries, a pronounced disparity becomes apparent when dissecting the data by winery size. Notably, in larger wineries, those with annual production capacities exceeding 500,000 L and staffing levels above 50 employees, a significant 80% demonstrate a clear, structured emphasis on EM practices. This is in stark contrast to their smaller counterparts, where such structured approaches are markedly less prevalent. Table 4 displays the environmental commitments and the environmental emergency scenarios that wineries have considered in their EMS categorized by their annual wine production capacity.

This distinction is particularly evident in the adoption of comprehensive EMSs, where larger wineries are more likely to have implemented sophisticated EMS frameworks, aligning closely with international standards such as ISO 14001:2015. Our analysis reveals that among the larger wineries, approximately 76% have either fully adopted or are in the process of implementing ISO 14001-certified systems, compared to a mere 24% among wineries with production capacities under 50,001 L per year.

Moreover, the commitment to EM in larger wineries extends beyond mere certification. These establishments often exhibit a more holistic approach to sustainability, incorporating advanced environmental planning, rigorous training programs, and robust leadership commitment. Our results indicate that nearly 80% of the larger wineries engage in regular environmental training sessions for their employees, which are aimed at fostering a culture of sustainability and ensuring compliance with environmental policies and practices. Figure 9 shows the percentage of wineries that have established an environmental policy, emergency plans, and ISO 14001:2015 by annual wine production categories.

Additionally, the strategic use of environmental communication stands out as a hallmark of larger wineries' EM efforts. A significant 90% of these wineries employ a diverse array of communication channels, both internal and external, to promote environmental awareness and report on sustainability initiatives. This includes the extensive use of digital platforms such as company websites, social media, and specialized environmental reports, ensuring a broad reach and engagement with various stakeholders, from employees and customers to regulatory bodies and the wider community. Figure 10 provides a clear depiction of how wineries communicate their environmental performance internally and externally, emphasizing the prevalence of digital and electronic communication methods in their communication practices.

Table 4. Environmental commitments and environmental emergency scenarios per annual wine production categories.

Annual Production	Environmental Commitments	Environmental Emergency Scenarios
<50,001 L/year	Reduce water use, reduce fuel use, control electricity use, reduce the use of fertilizers and pesticides	Presence of waste and/or abandoned waste, substance spill, fire
50,001 L/year–100,000 L/year	Reduce fuel use, reduce water use, control electricity use, Reduce the use of fertilizers and pesticides	Presence of waste and/or abandoned waste, substance spill, fire
100,001 L/year–250,000 L/year	Reduce water use, reduce fuel use, control electricity use, reduce the use of fertilizers and pesticides, reduce gas emissions, increase land use efficiency	Presence of waste and/or abandoned waste, irregular water discharge, fire
250,001 L/year–500,000 L/year	Reduce water use, control land use, reduce the use of fertilizers and pesticides, reduce gas emissions, packaging improvements (lighter bottles)	Presence of waste and/or abandoned waste, substance spill, irregular water discharge, fire
>500,000 L/year	Reduce water use, packaging improvements (lighter bottles), reduce paper use, control land use, reduce gas emissions, increase land use efficiency, improvements in wine distribution	Presence of waste and/or abandoned waste, irregular water discharge, substance spill, fire

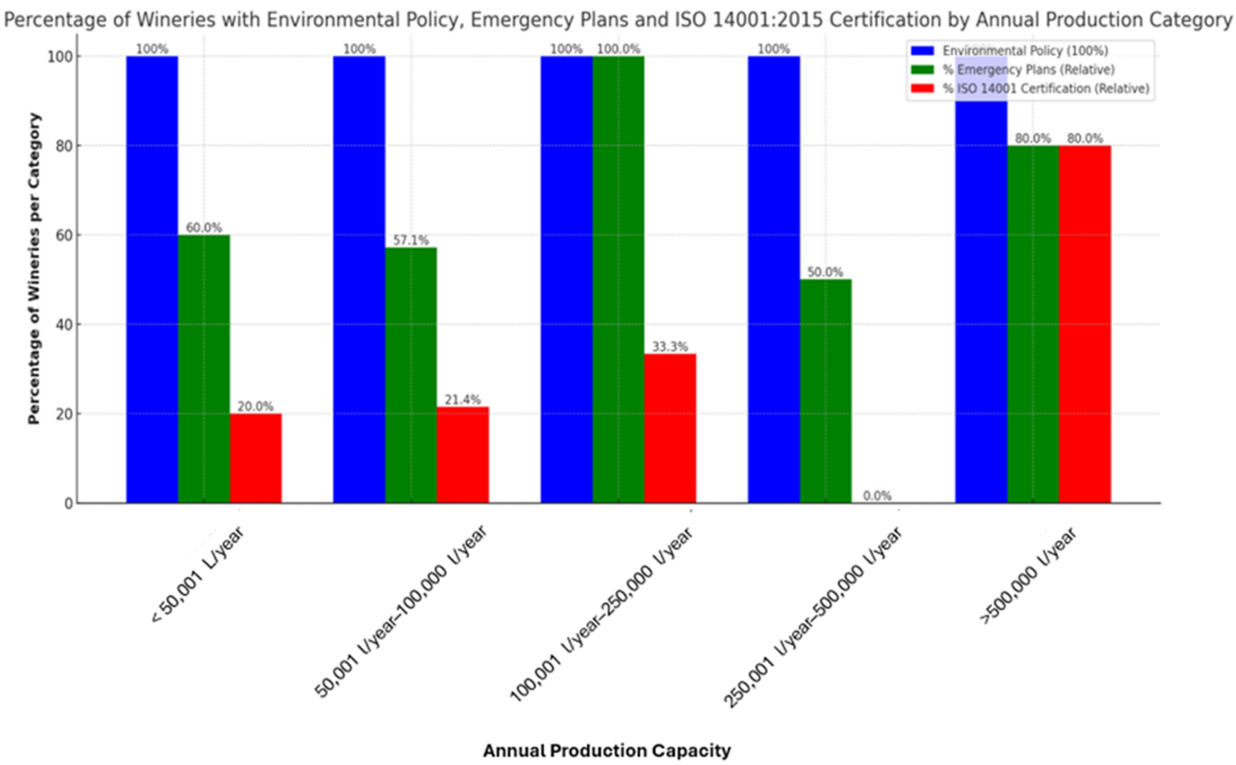

Figure 9. Percentage of wineries with an environmental policy, emergency plans, and ISO 14001 certification.

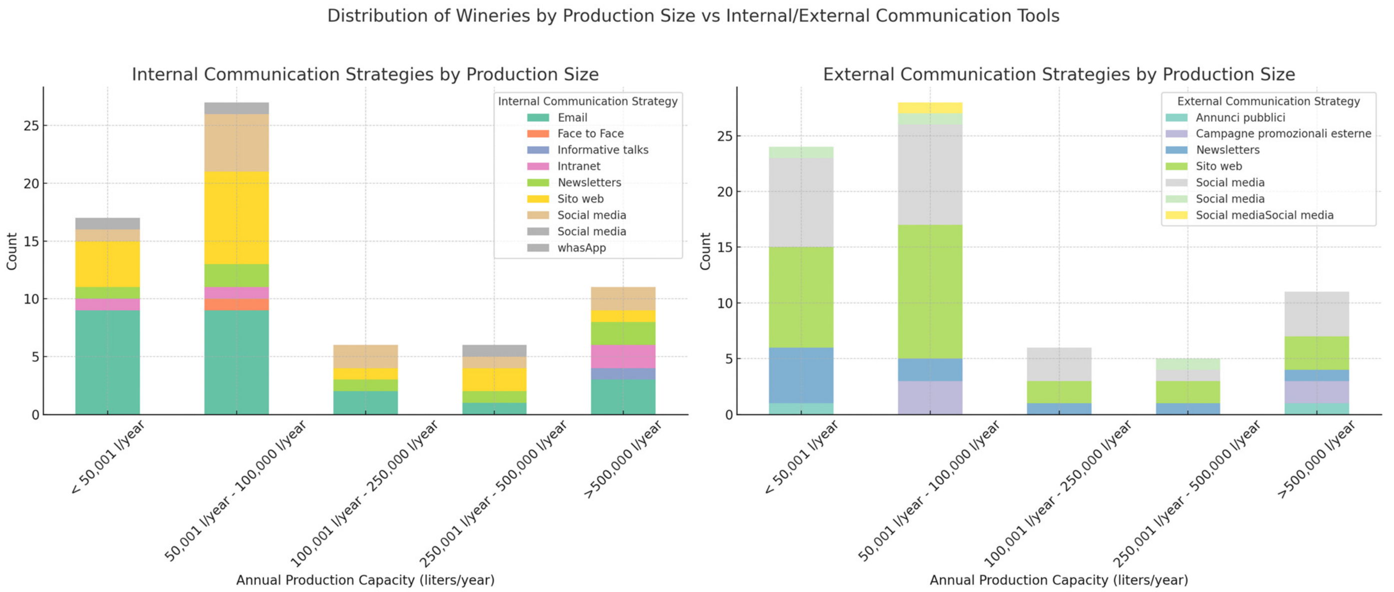

Figure 10. Internal/external environmental communication tools used by annual production categories.

Environmental communication practices, both internal and external, come under meticulous examination, revealing email as the most widely used internal communication medium (74.2%), followed by websites (45.2%) and social media (35.5%). External communication predominantly occurs through social media (84.4%) and websites (81.3%). Clients and shops emerge as the primary stakeholders receiving environmental information from wineries, emphasizing the pervasive use of Information and Communication Technologies (ICTs) for communication.

A substantial portion of wineries (71.9%) demonstrates the establishment of environmental policies and senior management leadership, with owners playing a pivotal role (50%). Key environmental objectives, such as waste and electricity consumption reduction, are identified, evaluating their alignment with long-term environmental policy commitments. A 68.8% of wineries have an EMS; however, certain deficiencies are highlighted, as evidenced by 38.7% of wineries lacking an Environmental Emergency Plan (EEP), and only 31.3% of wineries have their EMS certified according to the ISO 14001:2005 standard. The research underscores the paramount importance of these requirements for establishing a robust foundation for EM in winemaking.

The examination of environmental training for workers reveals that 71% of wineries provide training in connection with their EMS. Finally, five performance indicators assess the performance of wineries in communication, commitment, planning, other requirements, and workers' training. The results provide a comprehensive understanding of the state of EM practices in Italian wineries, shedding light on areas of strength and aspects that may require improvement.

Effectiveness in EM is achieved through the combination of five components: communication, commitment, planning, other requirements, and workers training.

3.4. FSMS Performance Indicators

Three performance indicators were derived in the context of case study two based on the three FS components encompassing worker training, adherence to legal rules, and surveillance of hazardous substances.

A quantitative analysis of FS worker training (FSWT) was performed based on an indicator defined by Equation (1) [58–60]:

$$W_{fswt} = (V_{G5} + V_{G6})/n \quad (1)$$

where

- W_{fswt} is the aggregated FSWT variable for the winery;
- V_{G5} is a variable that stands for the level of workers trained in GMPs and takes values 0.33, 0.66, or 1;
- V_{G6} is the variable that represents the level of workers trained in CCPs and takes values 0.33, 0.66, or 1;
- n is the number of variables that have been aggregated, and its value is 2.

A quantitative analysis of legislation identification and updating (LIU) was performed based on an indicator defined by Equation (2):

$$W_{liu} = (V_{ID1} + V_{ID2})/n \quad (2)$$

where

- W_{liu} is the aggregated LIU variable for the winery;
- V_{ID1} is a variable that stands for winery performance on legislation identification about arsenic, cadmium, and lead and takes values 0.33, 0.66, or 1;
- V_{ID2} is a variable that represents winery performance on updated legislation information through AESAN and takes values 0 or 1;
- n is the number of variables that have been aggregated, and its value is 2.

A quantitative analysis of critical control point chemical analysis performance (CCP-MCHEM) was evaluated based on an indicator defined by Equation (3):

$$W_{ccp\text{-}Mchem} = \left(V_{CS3} + V_{CBrx} + V_{CBry}\right)/n \quad (3)$$

where

- $W_{ccp\text{-}Mchem}$ is the aggregated CCP-MCHEM variable for the winery;
- V_{CS3} is a variable that stands for chemical information about arsenic, cadmium, and lead concentrations in the soil that a winery had; $V_{CS3} = \sum_{j=1}^{8} a_j$, a_j is each item of this multiple-choice question (yes = 0.125, no = 0);
- V_{CBrx} is a variable that represents the wineries' capacity to hold a chemical analysis by their own or external means. $V_{CBrx} = V_{CB2}$ if $V_{CB1} = 0$, otherwise, $V_{CBrx} = V_{CB1}$;
- V_{CBry} is a variable that stands for the wineries' capacity to hold arsenic, cadmium, and lead chemical analysis by their own or external means. $V_{CBry} = V_{CB4}$ if $V_{CB3} = 0$, otherwise, $V_{CBry} = V_{CB3}$;
- n is the number of variables that have been aggregated, and its value is 3.

3.5. EMS Performance Indicators

Five performance indicators were derived in the context of case study three based on the five EM components encompassing communication, commitment, planning, other requirements, and workers training.

A quantitative analysis of environmental communication was performed based on an indicator defined by Equation (4) [58,59]:

$$W_{ecm} = (V_{S23} + V_{S24} + V_{S25} + V_{S42})/n \quad (4)$$

where

- W_{ecm} is the aggregated communication variable for the winery;
- V_{S23} is the internal communication strategy variable of the winery; $V_{S23} = \sum_{j=1}^{6} a_j$, a_j is each item of this multiple-choice question (yes = 0.167, no = 0);
- V_{S24} is the external communication strategy variable of the winery; $V_{S24} = \sum_{j=1}^{6} b_j$, b_j is each item of this multiple-choice question (yes = 0.167, no = 0);

- V_{S25} is the stakeholder's variable to whom the winery communicates its environmental information of the winery; $V_{S25} = \sum_{j=1}^{6} c_j$, c_j is each item of this multiple-choice question (yes = 0.167, no = 0);
- V_{S42} is the environmental policy communication variable of the winery; $V_{S42} = \sum_{j=1}^{9} d_j$, d_j is each item of this multiple-choice question (yes = 0.125, no = 0);
- n is the number of variables that have been aggregated, and its value is 4.

A quantitative measure of environmental commitment was performed based on an indicator defined by Equation (5):

$$W_{ecx} = (V_{S41} + V_{S31} + V_{S32} + V_{S33})/n \quad (5)$$

where

- W_{ecx} is the aggregated commitment variable for each winery;
- V_{S41} is the winery environmental policy variable of the winery (yes = 1, no = 0);
- V_{S31} is the environmental director variable of the winery (yes = 1, no = 0);
- V_{S32} measures the senior management environmental system evaluation frequency (it could take one of next four values, 1 if (at least every six months), 0.75 (more than once a year), 0.50 (annually), and 0 (never reviewed));
- V_{S33} is the environmental evaluation procedure variable of the winery (yes = 1, no = 0);
- n is the number of variables that have been aggregated, and its value is 4.

A quantitative measure of environmental planning was performed based on an indicator defined by Equation (6):

$$W_{epx} = (V_{S21} + V_{S22} + V_{S43} + V_{S44} + V_{S51} + V_{S52} + V_{S53} + V_{S92} + V_{S93} + V_{S94})/n \quad (6)$$

where

- W_{epx} is the aggregated EM planning variable for each winery;
- V_{S21} measures the wineries' primary environmental objectives of the winery; $V_{S21} = \sum_{j=1}^{9} b_j$, b_j is each item of this multiple-choice question (yes = 0.112, no = 0);
- V_{S22} is the EM specific areas variable of the winery; $V_{S22} = \sum_{j=1}^{9} b_j$, b_j is each item of this multiple-choice question (yes = 0.112, no = 0);
- V_{S43} is the environmental commitments variable of the winery; $V_{S43} = \sum_{j=1}^{8} b_j$, b_j is each item of this multiple-choice question (yes = 0.125, no = 0);
- V_{S44} is the life cycle aspects variable; $V_{S44} = \sum_{j=1}^{3} b_j$, b_j is each item of this multiple-choice question (yes = 0.334, no = 0);
- V_{S51} is the winery energy consumption environmental aspect variable of the winery (yes = 1, no = 0);
- V_{S52} is the waste management performance environmental aspect variable of the winery (yes = 1, no = 0);
- V_{S53} is the fermentation emissions performance environmental aspect variable of the winery (yes = 1, no = 0);
- V_{S92} is the legal environmental requirements variable of the winery (yes = 1, no = 0);
- V_{S93} is the risk assessment variable (it could take one of the following three values: 1 if (quantitative method), 0.50 (qualitative method), and 0 (none));
- V_{S94} is the opportunity assessment variable (it could take one of the following three values: 1 if (quantitative method), 0.50 (qualitative method), and 0 (none));
- n is the number of variables that have been aggregated, and its value is 10.

A quantitative measure of other environmental requirements was performed based on an indicator defined by Equation (7):

$$W_{erx} = (V_{S61} + V_{S62} + V_{s63} + V_{S71} + V_{S72} + V_{S73} + V_{S101})/n \quad (7)$$

where

- W_{erx} is the aggregated other environmental requirements variable for each winery;
- V_{S61} is the EEP availability variable of the winery (yes = 1, no = 0);
- V_{S62} measures the kind of emergencies in the EEP of the winery; $V_{S62} = \sum_{j=1}^{6} b_j$, b_j is each item of this multiple-choice question (yes = 0.167, no = 0);
- V_{S63} measures the EEP evaluation frequency (it could take one of the following four values: 1 if (at least every six months), 0.75 (more than once a year), 0.50 (annually), and 0 (never reviewed));
- V_{S71} is the EMS document availability variable of the winery (yes = 1, no = 0);
- V_{S72} measures how the EMS information is recorded in the winery; $V_{S72} = \sum_{j=1}^{5} b_j$, b_j is each item of this multiple-choice question (yes = 0.2, no = 0);
- V_{S73} measures the document control frequency (it could take one of the following four values: 1 if (at least every six months), 0.75 (annually), 0.50 (more than once a year), and 0 (never reviewed));
- V_{S101} is the legal environmental requirements variable of the winery (yes = 1, no = 0);
- n is the number of variables that have been aggregated, and its value is 7.

A quantitative measure of environmental training for workers was performed based on an indicator defined by Equation (8):

$$W_{ewt} = (V_{S81} + V_{S82} + V_{S83})/n \quad (8)$$

where

- W_{ewt} is the aggregated environmental worker training variable for each winery;
- V_{S81} is the EMS workers training availability variable of the winery (yes = 1, no = 0);
- V_{S82} measures the workers training frequency (it could take one of the following four values: 1 if (at least every six months), 0.75 (annually), 0.50 (more than once a year), and 0 (never));
- V_{S83} measures the number of employees who participate in environmental training courses annually (it could take one of the following four values: 1 (more than 75%), 0.75 (between 50% and 75%), 0.50 (between 25% and 50%), and 0.25 (less than 25%));
- n is the number of variables that have been aggregated, and its value is 3.

3.6. Matrix of Sustainability Based on FS and EM

The sustainability matrix (SM), which illustrates the progress towards sustainability in wineries through FS and EM metrics, is formulated by integrating the findings from case studies two and three, respectively. The FS performance indicators, derived from the second case study, and the EM performance indicators, sourced from the third case study, collectively inform the matrix. Presented in Figure 11, the SM encapsulates the FSMS performance by averaging the scores from the winery sample in the second case study, alongside the EMS performance, which similarly utilizes the average scores from the third case study's winery sample. The matrix employs a color-coded scheme for ease of interpretation, where each indicator's value is depicted by a green line. The classification of sustainability progress is delineated as "Start" for indicator values ranging from 0 to 0.33, indicating initial stages; "In progress" for values from 0.34 to 0.67, denoting ongoing development; and "Maturity" for values from 0.68 to 1, signifying advanced integration of sustainability practices.

FSMS indicators, which cover aspects like worker training, legal compliance, and monitoring of hazardous substances, offer a comprehensive view of winery FS practices. The W_{fswt} indicator, which measures the extent of training in GMPs and CCPs, emphasizes the importance of thorough training in reducing contamination risks and ensuring wine safety. This indicator's high scores reflect wineries' substantial investment in training, indicating a deep-rooted culture of food safety. However, it also points to the ongoing need to update and expand training programs to meet new FS challenges and regulations.

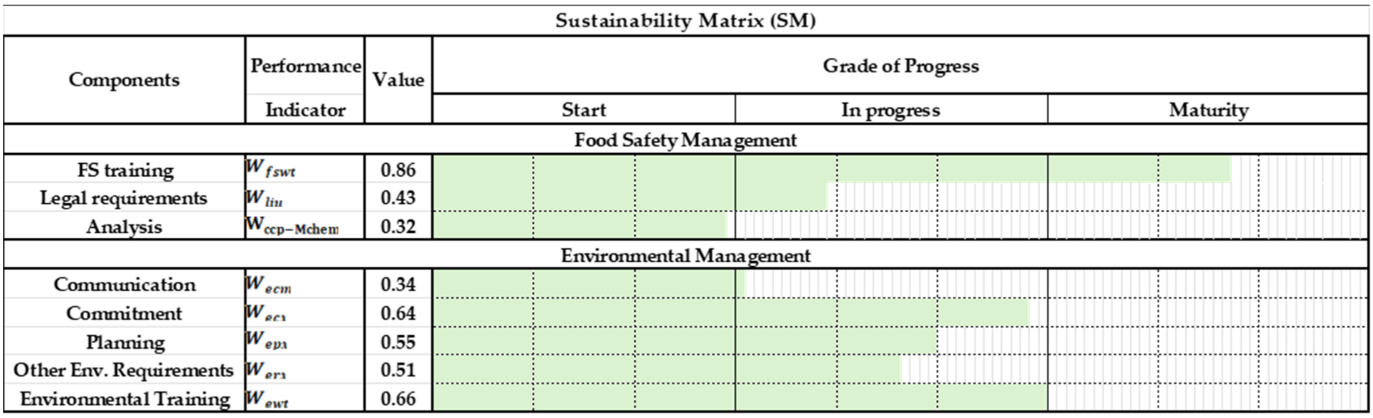

Figure 11. Sustainability matrix (SM) based on the performance of the FSMS and EMS.

The W_{liu} indicator assesses how well wineries keep up with laws concerning substances like arsenic, cadmium, and lead. The intermediate scores here show a moderate level of legal awareness and compliance, suggesting a gap in knowledge sharing and the need for stronger systems to keep wineries informed about food safety laws.

The $W_{ccp\text{-}Mchem}$ indicator evaluates the ability to analyze chemical hazards, a key part of FS. Its lower scores indicate room for improvement in analytical capabilities and the adoption of more thorough testing methods to proactively manage contamination risks.

These FS indicators collectively offer a detailed look at the strengths and areas for improvement in winery FS practices, aligning with wider sustainability goals and ensuring consumer health and safety. This analysis highlights the intricate relationship between training, compliance, and hazard management in creating a strong FS framework that is crucial for sustainable and responsible wine production.

Turning to EM indicators, the W_{ecx} and W_{ewt} quantitatively reflect wineries' sustainability efforts. For example, the W_{ecx} score of 0.64 signals a strong commitment to environmental sustainability through established policies and active management, though there is room to increase the frequency of EMS reviews. The W_{ewt} score, close to the "Maturity" level at 0.66, points to the significant role of environmental training in wineries, suggesting solid groundwork with potential for further growth. The W_{epx} indicates ongoing environmental planning efforts, though the need for better alignment, especially regarding fossil fuel consumption, suggests areas for strategic improvement. The W_{erx} indicator shows a moderate implementation level (0.51) of additional environmental management practices, with variations in emergency preparedness and documentation control indicating the need for more consistent management approaches. W_{ecm}, with a low score in the "In progress" category (0.34), highlights a lack of effective communication strategies in environmental management, suggesting that wineries could benefit from better internal and external communication of their environmental policies and practices to enhance EM effectiveness.

Analyzing the distribution of these eight indicators within these categories reveals the nuanced progress wineries have made toward sustainability. For example, the "In progress" status for many indicators suggests a significant potential for improvement, especially in legal requirements and physicochemical analysis for FS and in commitment and environmental training for EM. This nuanced interpretation can inform targeted strategies for wineries to enhance their sustainability practices.

The alignment of the SM with the F2F Strategy's objectives is crucial. The matrix's indicators can be directly linked to F2F goals such as reducing the environmental footprint, ensuring FS, and promoting sustainable practices. The SM not only serves as a diagnostic tool but also guides strategic decision-making for wineries. By identifying areas of strength and potential improvement, the SM can inform targeted interventions. For example, wineries scoring lower in the workers training component (W_{ewt}) might invest more in training programs, while those with lower environmental commitment scores might focus on enhancing their EMS policies and management engagement.

4. Discussion

The wine production industry, like other agricultural sectors, must undergo transformative evolution to align with sustainability objectives. Effectively integrating sustainability into wine production demands methodical approaches, considering the intricate challenges and opportunities inherent in the process. Strategies such as FS assurance, responsible agricultural practices, and the reduction of environmental impacts are identified as pivotal for wineries [61,62].

An in-depth investigation into FS reveals substantial variations in the control performance of thirty-seven CCPs and oPRPs assessed during the wine production process. Out of these thirty-seven elements, twenty-two received favorable evaluations, while fifteen exhibited notable performance disparities based on specific practices within each winery.

It is imperative to underscore that significant control deficiencies observed in wineries were associated with various aspects, including the management of trace metals, fungicides, and pesticides in grapes or wine from a chemical perspective. Similarly, deficiencies in biological controls, such as microorganisms on equipment, and operational stage controls, like the duration of must in crushers, demonstrated suboptimal performance. In instances where both CCPs and oPRPs are inadequately controlled, there is an increased risk of potential hazards, such as the presence of microorganisms, trace metals, fungicides, pesticides, or other hazardous substances in grapes or wine [42,63,64].

Performance indicators play a fundamental role in assessing the sustainability of wineries in terms of FS, enabling the measurement of the effectiveness of risk management practices.

Illustrating the importance of indicators in FS is the training component W_{fswt}. The "Maturity" grade of progress indicates that wineries have achieved an advanced stage in the training component. This suggests a shared commitment among wineries to invest in training to address contamination risks effectively. These findings align with research emphasizing the significance of aspects related to FS culture, particularly concerning human factors and specialized training [65,66].

Progress in the legislation component is measured by W_{liu} and shows a performance level of "In progress" (0.43). This emphasizes the need for greater knowledge and compliance with European legislation related to FS concerning the risks of contamination by heavy metals. The progression in legislation-related activities is a crucial aspect in ensuring compliance and addressing contamination risks.

Progress in the analysis component is reflected by achieving a "Start" level in $W_{ccp\text{-}Mchem}$. The analysis component, crucial for identifying and controlling the presence of arsenic, cadmium, and lead in grapes and wines, is considered the least mature in terms of performance. Wineries need to focus more on progressing in the legislation and analysis components to enhance their ability to manage contamination risks effectively and thus achieve greater progress in their sustainability.

Hence, the sustainability of wineries in terms of FS is currently classified as "In progress", with considerable scope for improvement, particularly in the components of legal requirements and analysis. Our results are aligned with the pros and cons of sustainable wine production found by Szolnoki, G. [26].

EM research reveals that main environmental objectives, focusing on waste, electricity, and water reduction, emerge as central to sustainability efforts. However, there is a need for more consistent alignment between long-term commitments and annual objectives. Wineries prioritize objectives such as waste reduction, electricity, and water consumption reduction, aligning with their sustainability goals. However, there is room for improvement in synchronizing with fossil fuel consumption objectives. These findings align with other studies about environmental aspects and impacts in the winemaking process and measures to reduce them [67–69].

Emergency preparedness varies, with 38.7% lacking plans, emphasizing the need for improvement. The results reveal that the significance of ISO 14001:2015 certification is low, which is in line with other studies conducted in the Italian wine sector [70,71].

Environmental performance indicators provide insights into the progress of sustainability concepts, reflecting their global commitment to enhancing environmental sustainability. The communication component indicator (W_{ecm}) reveals a lack of progress as evidenced by a value corresponding to the "Start" grade of progress (0.34). It is imperative for wineries to concentrate on refining their communication strategies to improve overall EM effectiveness.

The environmental commitment indicator (W_{ecx}) achieves a 0.64 that corresponds to an "In progress" grade of performance. It exhibits a robust commitment to environmental sustainability through well-established policies and dedicated senior management teams, although the frequency of EMS reviews varies. Carrillo Higueras et al. [72] found that winery managers consider their own attitudes towards the environment and their perceptions of control as the most important factors when adopting environmental commitment in their organization.

The planning component indicator (W_{epx}) reveals a landscape where "In progress" grades of progress are prevalent, indicating continual efforts in environmental planning across wineries. However, there is room for improved alignment, especially in fossil fuel consumption objectives. Findings are aligned with the research study recommendations obtained by Gierling F. et al. [73], and it is also in agreement with a previous study conducted by Carronquino J. et al. [74], since environmental planning has not been sufficient to promote adaptation and mitigation to climate change.

Other requirements (W_{erx}) generally show that wineries are "In progress" in implementing other EM requirements. Emergency preparedness varies, with 38.7% lacking plans, emphasizing the need for improvement. Organizing and controlling documentation is crucial for nearly a hundred percent of wineries, with half of them updating it annually to align with ISO 14001, emphasizing their commitment to EM traceability through the document system. Nevertheless, one-third of wineries fall short in completing this yearly updating process, presenting an opportunity for improvement in maintaining their EMS documentation.

The workers training component (W_{ewt}) currently indicates an "In progress" status with a progress level of 0.66. This level closely approaches "Maturity", underscoring the significance of environmental training for wineries. These findings highlight the critical role of environmental training in the winemaking industry.

The sustainability of wineries in terms of EM is at a stage of medium progress, with components such as commitment and environmental training approaching maturity. These findings align with the research on environmental sustainability in wineries conducted by Baiano A. (2021) [53].

Our research reveals critical insights essential for advancing the wine sector. The sustainability of wineries in terms of FS is presently described as "In progress", signifying a significant potential for improvement, particularly in the facets of legal requirements and analysis. This implies that wineries must enhance their compliance with FS regulations and refine their physicochemical analysis processes to boost FS outcomes. In terms of the sustainability of wineries, EM is observed to be at a moderate level of advancement. Notably, elements like the commitment to sustainability and environmental training are on the verge of reaching full maturity, indicating a growing recognition and incorporation of environmental considerations into the operational principles of wineries. These findings highlight the differentiated progress in the winery industry towards sustainability, pointing out specific areas where focused initiatives can lead to more substantial improvements.

5. Conclusions

Against the backdrop of global concerns about the sustainability of agricultural and food production, the EU policy emerges with a central focus through the F2F Strategy, emphasizing the need for a paradigm shift towards principles that seamlessly integrate environmental preservation, FS, and nutritious sustenance.

In this context, the concept of sustainability necessitates interpretation through methods capable of quantifying its evolution and progress within wineries. This comprehensive exploration of sustainability in wineries, which is in alignment with the F2F Strategy and considers both FS and EM perspectives, sheds light on crucial aspects requiring attention and improvement within the wine production industry.

This study underscores the imperative for the wine production industry to undergo transformative evolution, aligning with sustainability objectives in line with the goals of the F2F Strategy. Actions such as FS assurance and environmental impact reduction are identified as pivotal for wineries in achieving sustainability.

The SM is composed of the performance indicators of wineries in different components of sustainability in terms of FS and EM, and it plays a fundamental role in assessing wineries' approach to F2F Strategy goals. SM provides a comprehensive framework for wineries to evaluate their efforts for being more sustainable, addressing specific areas requiring focused attention and improvement in both FS and EM dimensions.

Protected Designations of Origin, cooperatives, and regulatory bodies can play a key role in supporting sustainability development by proposing incentives such as rewards or public subsidies for wineries that demonstrate better performance in FM and EM. By using the proposed SM as an evaluation tool, these entities can establish clear and objective criteria to measure the commitment and effectiveness of sustainable practices in the wine sector, thus promoting continuous improvement and recognizing significant efforts towards a more sustainable future.

Leadership plays a crucial role in establishing a strong culture towards sustainability within wineries, where owners and managers must lead by example, showing unwavering commitment to the effectiveness of FSMSs and EMSs. This dedication not only fosters an environment where all workers feel motivated to align with the objectives of senior management but also facilitates the identification of strengths and areas susceptible to improvement. By doing so, it enriches the perspective on the various approaches adopted by the industry and the level of commitment to sustainability, which is vital for promoting safer and more sustainable practices in the wine sector.

Finally, there is ample opportunity to further study and delve into the methodology of indicators calculation and its application to other sectors within the agro-industry. The application of artificial intelligence based on machine learning and neural networks emerges as a promising approach. These techniques have the capability to enhance existing indicators by incorporating new attributes, aiming to facilitate the prediction of sustainability. This process involves expanding the predictive capacity through the identification and evaluation of additional factors that impact sustainability in this specific context. The deployment of these advanced methodologies opens the door to a deeper and more precise understanding of sustainable aspects in the operations of wineries and other agro-industrial entities, thereby providing a more comprehensive and anticipatory approach to sustainability management in these sectors.

Author Contributions: Conceptualization, J.L.-S., A.M.S. and M.T.G.-V.; methodology, J.L.-S., F.A.B.M.Y., F.R.M. and M.T.G.-V.; validation, J.L.-S., F.R.M. and M.T.G.-V.; formal analysis, J.L.-S.; investigation, J.L.-S. and M.T.G.-V.; data curation, J.L.-S.; writing—original draft preparation, J.L.-S.; writing—review and editing, J.L.-S., A.M.S., F.A.B.M.Y., F.R.M. and M.T.G.-V.; supervision, A.M.S., F.A.B.M.Y., F.R.M. and M.T.G.-V. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data used in this study are available on fair request to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Appendix A.1. Survey for the Analysis of Implementation and Deployment of HACCP System in Wineries Producing Red Wine

* Indicates That the Question is Mandatory
Email Address *

G.0 What is your annual production level of young red wine? Mark only one oval.

- ○ up to 25,000 L/year
- ○ between 25,001 and 100,000 L/year
- ○ between 100,001 and 250,000 L/year
- ○ between 250,001 and 500,000 L/year
- ○ more than 500,001 L/year

G.1 Have you implemented a prerequisite program according to the food hygiene legislation?* Mark only one oval.

- ○ Yes
- ○ No

G.2 Indicate which type of prerequisite plans you have implemented. * Select all that apply.

- ☐ G.2.1 Maintenance of premises, facilities, and equipment
- ☐ G.2.2 Good Manufacturing Practices Plan
- ☐ G.2.3 Cleaning and disinfection plan
- ☐ G.2.4 Waste control plan
- ☐ G.2.5 Pest control plan
- ☐ G.2.6 Control plan for water supply
- ☐ G.2.7 Traceability control plan
- ☐ G.2.8 Supplier control plan
- ☐ G.2.9 Allergen control plan
- ☐ G.2.10 Worker training plan

G.3 Do winery operators have training related to good viticulture practices (BPV)?* Mark only one oval.

- ○ No operator has BPV training.
- ○ More than half of the operators have BPV training.
- ○ All operators have BPV training.

G.4 Do winery operators know the prerequisite plans implemented in the winery? Mark only one oval.

- ○ No operator is aware of the implemented prerequisite plans.
- ○ More than half of the operators are aware of the implemented prerequisite plans.
- ○ All operators are aware of the implemented prerequisite plans.

G.5 Does the winery have a specific annual budget for the execution of the prerequisite plans?* Mark only one oval.

- ○ The winery does not have an annual budget for this matter.
- ○ The winery carries out plans as needed but does not have a detailed annual budget.
- ○ The winery has a detailed annual budget, which it executes in a planned manner.

G.6 Has the winery implemented a Hazard Analysis and Critical Control Point (HACCP) System?* Mark only one oval.

- ○ Yes
- ○ No

Harvest and Transportation

2.1 Are periodic inspections carried out in the vineyards prior to the harvest?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

2.2 Are inspections conducted in the vineyards during the harvest to control hygiene measures during this stage?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

2.3 Is the time taken to transport grapes destined for the production of red wine measured from the vineyard to the winery?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

Receipt of the harvest at the winery

3.1 Is the measurement of residues of fungicides and/or pesticides in grapes destined for the production of red wine carried out when received at the winery?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

3.2 Is the presence of mycotoxins from rotting grapes checked?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

3.3 Is the presence of contamination by metals (cadmium, lead, arsenic) in grapes checked?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

3.4 Is the presence of contamination by vegetable residues, dust, and/or metallic elements in grapes checked?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

Pre-fermentation Treatments

4.1 Is the cleanliness of tanks controlled to eliminate residues of microorganisms?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

4.2 Is the absence of cleaning and disinfection products from performing these tasks in the tanks controlled?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

Grape Crushing and Paste Pumping

5.1 Is it controlled that the maintenance time of the must in the crusher is less than two hours?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

5.2 Is the cleanliness of the crushing equipment controlled with a frequency not exceeding two days?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

5.3 Is the absence of cleaning and disinfection products from performing these tasks in the tanks, press, and/or pumping equipment controlled?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

Sulfiting and Fermentation

6.1 Is the safety and purity of additives controlled?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

6.2 Is the absence of microorganisms in the equipment and tanks controlled?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

Alcoholic Fermentation, Maceration, Racking, Pressing of Grape Pomace, Malolactic Fermentation, and Finishing Fermentation

7.1 Is the concentration of ethyl carbamate in the fermented must controlled?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

7.2 Is the concentration of sulfur dioxide in the fermented must controlled?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

7.3 Is the purity and safety of yeasts controlled?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

7.4 Is the temperature controlled during fermentation?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

7.5 Is the pH of red wine controlled during malolactic fermentation?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

7.6 Is hygiene controlled during racking and pressing operations?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

7.7 Is the cleanliness of pressing equipment controlled with a frequency not exceeding two days?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

Racking, Clarification, and Filtration

8.1 Are the cleaning procedures for tanks and racking equipment controlled?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

8.2 Are the maintenance and cleaning procedures of the facilities controlled during the racking stage?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

8.3 Is the purity and safety of the agents used as clarifiers in red wine controlled?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

8.4 Is the absence of residues from the agents used as clarifiers in red wine controlled?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

8.5 Is the absence of foreign elements from the filters in red wine controlled?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

8.6 Are hygiene operations controlled during clarification and filtration operations?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

8.7 Is the absence of cleaning and disinfection products from racking, clarification, and filtration tasks in tanks and/or equipment controlled?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

Cold Stabilization

9.1 Are the limit concentrations of metals (traces of As, Cu, Pb) in red wine controlled?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

9.2 Is it controlled that the additives used are those allowed by current food legislation?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

Bottling and Labeling

10.1 Are bottle cleaning procedures controlled?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

10.2 Are maintenance and cleaning procedures for the red wine bottling line controlled?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

10.3 Is there microbiological control of the red wine bottling line and bottles?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

10.4 Is it controlled that the cork or a similar plug used for closing the bottles has undergone microbiological control?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

10.5 Is it controlled that the label used is correctly coded?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

10.6 Is it controlled that the label used correctly describes mandatory information about allergens?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

10.7 Is it controlled that the label used correctly describes information about the Denomination of Origin Vinos de Madrid?* Mark only one oval.

Never (0)/Hardly ever (1)/Usually (2)/Always (3).

Application of HACCP Principles

11.1 Have the winery's managers set objective and critical limit levels for each of the identified critical points?* Mark only one oval.

- ○ No, for none of them.
- ○ Yes, but only for those where applicable mandatory regulations exist.
- ○ Yes, for each and every one of them following applicable mandatory regulations and/or professional technical recommendations.

11.2 Has the winery established a monitoring system for critical control points?* Mark only one oval.

- ○ Yes
- ○ No

11.3 If a CCP monitoring system is established, what checking methods are used?* (Check all that apply from the following list). Select all that apply.

- ○ Visual observation
- ○ Sensory evaluation (smell, taste, aroma, texture)
- ○ Physical determinations (temperature, relative humidity, pH)
- ○ Chemical analysis

- ○ Microbiological analysis

11.4. Does the winery have a written monitoring program detailing the surveillance activities of hazards and their CCPs at each stage of red wine production? ?* Mark only one oval.

- ○ Yes
- ○ No

11.5 Does the winery have a written procedure for establishing corrective measures to be applied in case of deviations in each critical control point (CCP)?* Mark only one oval.

- ○ Yes
- ○ No

11.6 Does the winery have a procedure for verifying the effectiveness of the CCP control system? ?* Mark only one oval.

- ○ Yes
- ○ No

11.7 If yes, does this verification procedure detail the frequency of control for each critical control point (CCP) and the person in charge of performing it? ?* Mark only one oval.

- ○ Yes
- ○ No

11.8 If yes, please indicate which people are involved in verifying the effectiveness of the CCP system. Check all options that apply.

- ○ Winery owner
- ○ Winery manager
- ○ Quality manager or similar
- ○ Winemaker
- ○ Operators
- ○ Others

11.9 Does the winery conduct an annual internal audit of the Critical Control Points (CCPs) and control analysis?* Mark only one oval.

- ○ No
- ○ Yes, but with a frequency greater than one year.
- ○ Yes, annually.

11.10 Does the winery have a record and documentation system for the HACCP system? ?* Mark only one oval.

- ○ There are no records or written documents.
- ○ Yes, there are records and written documents, but they are not complete or not updated periodically.
- ○ Yes, there is a complete and periodically updated record and documentation system.

11.11 If yes, what documents does the winery's HACCP system contain? (Check all options that apply)

- ○ List of HACCP system team members
- ○ Description of stages and production process of red wine
- ○ Analysis of hazards and determination of preventive measures
- ○ Identification of Critical Control Points (CCP)
- ○ Surveillance program containing surveillance activities
- ○ Corrective measures procedure
- ○ Results of verifications and internal audits
- ○ Document and record management procedure
- ○ Records generated by the HACCP system.

Appendix A.2. Analysis of Wineries Performance about Critical Control Points Related to Risk Control Contamination by Arsenic, Cadmium, and Lead in Grapes/Wines during Winemaking

* Obligatory
General data of the winery

G.1 What is your annual level of red wine production?* (Mark only one)

up to 25,000 L/year
between 25,001 and 100,000 L/year
between 100,001 and 250,000 L/year
between 250,001 and 500,000 L/year more than 500,001 L/year

G.2 Do you have a prerequisite program in place, according to the legislation on food hygiene?* (Mark only one)

Yes/No

G.3 Does the winery have a Hazard Analysis and Critical Control Point (HACCP) system in place?* (Mark only one)

Yes/No

G.4 How many people work in wine production operations in the winery?*

G.5 Do winery workers have training about good manufacturing practices (GMPs)?* (Mark only one)

No worker has GMP training.
More than half of workers have GMP training.
All workers have GMP training.

G.6 Do winery workers have control training and monitoring of critical points (CCPs)?* (Mark only one)

No worker has training in the controlling and monitoring of CCPs.
More than half of workers have training in control and monitoring of the CCPs.
All workers have training in control and monitoring of the CCPs.

Information available on arsenic, cadmium, and leads in the raw material (Critical Control Point)

ID 1. The winery has identified the legislation relating to food contamination by the following: (check all those you consider).

Arsenic/Cadmium/Lead

ID 2. The winery uses the updated information available from the Spanish Agency for Food Safety and Nutrition (AESAN) on heavy metals food risk. * (Mark only one)

Yes/No

CS 1. Does the winery have information related to the physical-chemical analysis of where do the grapes used in winemaking come from?* (Mark only one)

Yes (Skip to question 11)/No

CS 2. Does the winery have information on the fertilizers used in the fertilization of the soil from which the grapes used in winemaking come from?* (Mark only one)

Yes/No

Information available on the concentration of arsenic, cadmium, and lead in the soil

CS 3. The available information on the analysis of vineyard arable soil holds data on the following:

Select all that apply.

Total Arsenic Concentration in Soil
Concentration of Arsenic Available in Soil
Total Cadmium Concentration in Soil
Cadmium Concentration Available in Soil
Total Lead Concentration in Soil
Lead Concentration Available in Soil
Soil pH
Electrical conductivity of the soil

Control of the raw material (analysis procedures in the winery)

CB 1. Does the winery have its own laboratory to perform a chemical analysis of grapes and wines?* (Mark only one)

Yes/No

CB 2. If you do NOT have your own laboratory, do you use an external laboratory to perform a chemical analysis of grapes and wines?* (Mark only one)

Yes/No

CB 3. Does the warehouse have the technology and personnel to perform a metal analysis using atomic absorption spectrometry?* (Mark only one)

Yes/No

CB 4. If you do NOT have your own laboratory, do you use an external laboratory to perform a metal analysis using atomic absorption spectrometry on grapes and wines?*

Yes/No

Professional profile that performs the survey
You can tell us about your job inside the winery. (Mark only one)

Owner
Director/Manager
Winemaker
Winery Operator
Administrative/management/commercial staff
Other

Appendix A.3. Environmental Management System Questionnaire (Italy)

* Obligatory

1. Company name *
2. E-mail address *
3. S1.1 Annual production capacity. Mark only one oval.
   - ○ Less than 50,001 L/year.
   - ○ 50,001 L/year—100,000 L/year.
   - ○ 100,001 L/year—250,000 L/year.
   - ○ 250,001 L/year—1,000,000 L/year.
   - ○ More than 1,000,000 L/year.
4. S1.2 Number of employees. Mark only one oval.
   - ○ <10.
   - ○ 10 to 49.
   - ○ 50 to 249.
   - ○ 250.
5. S1.3 Job position in the company. Mark only one oval.
   - ○ General Manager.
   - ○ Owner Manager.

- ○ Ecological Manager.
- ○ Administration Officer.
- ○ Vineyard Manager Executive Director.
- ○ Other

6. S2.1 What are the company's main environmental objectives? Select all that apply.
    - ○ Electricity consumption reduction.
    - ○ Water consumption reduction.
    - ○ Land use reduction.
    - ○ Greenhouse gas emissions reduction.
    - ○ Other gas emissions reduction.
    - ○ Waste production reduction.
    - ○ Use of raw materials reduction.
    - ○ Substances released into the soil reduction.
    - ○ Other
7. S2.2 Does the company have any of the following areas/departments? Select all that apply.
    - ○ Environmental Management.
    - ○ Leadership.
    - ○ Planning of environmental objectives.
    - ○ Environmental risk and opportunities.
    - ○ Resources and environmental support.
    - ○ Communication.
    - ○ Operation and environmental control.
    - ○ Emergency response.
    - ○ Monitoring, analysis, and evaluation of EMS performance.
8. S2.3 What is the company's internal communication strategy? Select all that apply.
    - ○ Website.
    - ○ Email.
    - ○ Social media (Facebook, Instagram, etc.).
    - ○ Newsletters.
    - ○ Internal staff site.
    - ○ Other
9. S2.4 What is the company's external communication strategy? Select all that apply.
    - ○ Website.
    - ○ Social media (Facebook, Instagram, etc.).
    - ○ Newsletters.
    - ○ Advertisement.
    - ○ Marketing campaigns.
    - ○ Other
10. S2.5 Does the company disclose environmental information to any stakeholders? Select all that apply.
    - ○ Clients.
    - ○ Ecology associations.
    - ○ Public administrations.
    - ○ Suppliers.
    - ○ Shops.
    - ○ Other
11. S3.1 Has the organization clearly identified the Environmental Director in the company? Mark only one oval.
    - ○ Yes.
    - ○ No.

12. S3.2 How often does the senior management review the organization's environmental management system? Mark only one oval.
    - ○ At least every six months.
    - ○ Annually.
    - ○ Over a year.
    - ○ Never.
13. S3.3 Has the company established processes to achieve annual environmental results? Mark only one oval.
    - ○ Yes.
    - ○ No.
14. S4.1 Has the company established an environmental policy? Mark only one oval.
    - ○ Yes.
    - ○ No.
15. S4.2 How does the company communicate and/or promote its environmental policy? Select all that apply.
    - ○ Website. Newsletter. Social Media. Advertisement.
    - ○ E-mail promotional. Marketing campaigns.
    - ○ Courses
    - ○ None of these
    - ○ Other
16. S4.3 Does the company's environmental policy include any of these commitments? Select all that apply.
    - ○ Reduce the use of water.
    - ○ Reduce the use of fossil combustible.
    - ○ Control of electricity use.
    - ○ Reduce fertilizer and pesticide use.
    - ○ Reduce gas emissions.
    - ○ Increasing land use efficiency.
    - ○ Improvement in packaging (glass bottles).
    - ○ Improvement in wine distribution.
17. S4.4 What aspects of the life cycle are included in environmental policy? Select all that apply.
    - ○ Environmental impacts of the supply chain.
    - ○ Environmental impacts of product use.
    - ○ Environmental impacts of waste generation.
18. S3.4 Who is responsible for environmental management? Mark only one oval.
    - ○ Owner
    - ○ General Manager
    - ○ Environmental Manager
    - ○ Administrative Manager
    - ○ Vineyard Director
    - ○ Executive Director
    - ○ Other:
19. S5.1 Considering that wineries have a high energy consumption, what actions or measures does the company take to reduce the environmental impact?
20. S5.2 Wineries generate a lot of solid waste, which, once disposed of, has a high environmental impact. How is this high amount of waste managed?
21. S5.3 Wineries generate gases that are usually impregnated with fruit or machinery. What processes should be in place to reduce these emissions and therefore generate less impact?

22. S6.1 Has the company prepared plans to prevent or mitigate negative environmental impacts resulting from emergency situations? Mark only one oval.
    - ○ Yes.
    - ○ No.
23. 6.2 If so, which environmental emergency is the company prepared for? (Select one or more). Select all that apply.
    - ○ Fire
    - ○ Water uncontrolled discharge with a cleaning product or organic matter residues.
    - ○ Water drains with chemical contaminants.
    - ○ Landfilling of waste and/or abandoned waste.
    - ○ Leakage of dangerous substances.
    - ○ Other
24. S6.3 Does the company periodically review planned response actions for emergency situations? Mark only one oval.
    - ○ At least every six months.
    - ○ Annually.
    - ○ Over a year.
    - ○ Never.
25. S7.1 Does the organization have documented information to demonstrate that it monitors, measures, and evaluates its environmental performance? Mark only one oval.
    - ○ Yes.
    - ○ No.
26. S7.2 How does the organization record information to demonstrate that it evaluates the effectiveness of its environmental management system? Select all that apply.
    - ○ Data records.
    - ○ Reports.
    - ○ Technical Instructions.
    - ○ Procedures.
    - ○ None of these.
    - ○ Other.
27. S7.3 How often does the company create and update documented information consistent with its environmental management system? Mark only one oval.
    - ○ At least every six months.
    - ○ Annually.
    - ○ Over a year.
    - ○ Never.
28. S9.2 Does the company have legal requirements from government bodies or other relevant authorities in relation to environmental impacts? Mark only one oval.
    - ○ Yes.
    - ○ No.
29. S8.1 Is training offered to staff on environmental management systems? Mark only one oval.
    - ○ Yes.
    - ○ No.
30. S8.2 If so, how often do staff take these environmental trainings? Mark only one oval.
    - ○ At least every six months.
    - ○ Annually.
    - ○ Over a year.
    - ○ Never.

31. S8.3 How many workers have already undergone environmental management training? Mark only one oval.
    - ○ Less than 25%
    - ○ Between 25–50%
    - ○ Between 50–75%
    - ○ More than 75%
32. S9.3 What method does the organization use to carry out risk analysis? Mark only one oval.
    - ○ Quantitative method
    - ○ Qualitative method
    - ○ None
33. S9.4 What method does the organization use to perform the opportunity analysis? Mark only one oval.
    - ○ Quantitative method
    - ○ Qualitative method
    - ○ None
34. S10.1 Has the company certified its EMS with ISO 14001:2015? Mark only one oval.
    - ○ Yes.
    - ○ No.

References

1. Wesseler, J. The EU's farm-to-fork strategy: An assessment from the perspective of agricultural economics. *Appl. Econ. Perspect. Policy* **2022**, *44*, 1826–1843. [CrossRef]
2. Schebesta, H.; Candel, J.J. Game-changing potential of the EU's Farm to Fork Strategy. *Nat. Food* **2020**, *1*, 586–588. [CrossRef]
3. European Commission. *The European Green Deal*; Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committe and The Committe of the Regions. COM(2019) 640 final; European Union: Brussels, Belgium, 2019.
4. Schebesta, H.; Bernaz, N.; Macchi, C. The European Union Farm to Fork Strategy. *Eur. Food Feed Law Rev.* **2020**, *15*, 420–427.
5. Billen, G.; Aguilera, E.; Einarsson, R.; Garnier, J.; Gingrich, S.; Grizzetti, B.; Lassaletta, L.; Le Noë, J.; Sanz-Cobena, A. Beyond the Farm to Fork Strategy: Methodology for designing a European agro-ecological future. *Sci. Total Environ.* **2024**, *908*, 168160. [CrossRef]
6. Sadiku, M.N.; Musa, S.M.; Ashaolu, T.J. Food industry: An introduction. *Int. J. Trend Sci. Res. Dev.* **2019**, *3*, 128–130. [CrossRef]
7. Yadav, V.S.; Singh, A.R.; Gunasekaran, A.; Raut, R.D.; Narkhede, B.E. A systematic literature review of the agro-food supply chain: Challenges, network design, and performance measurement perspectives. *Sustain. Prod. Consum.* **2022**, *29*, 685–704. [CrossRef]
8. Hammoudi, A.; Hoffmann, R.; Surry, Y. Food safety standards and agri-food supply chains: An introductory overview. *Eur. Rev. Agric. Econ.* **2009**, *36*, 469–478. [CrossRef]
9. Lezoche, M.; Hernandez, J.E.; Díaz, M.d.M.E.A.; Panetto, H.; Kacprzyk, J. Agri-food 4.0: A survey of the supply chains and technologies for the future agriculture. *Comput. Ind.* **2020**, *117*, 103187. [CrossRef]
10. Luo, J.; Ji, C.; Qiu, C.; Jia, F. Agri-Food Supply Chain Management: Bibliometric and Content Analyses. *Sustainability* **2018**, *10*, 1573. [CrossRef]
11. Amin-Chaudhry, A.; Young, S.; Afshari, L. Sustainability motivations and challenges in the Australian agribusiness. *J. Clean Prod.* **2022**, *361*, 132229. [CrossRef]
12. Gold, S.; Kunz, N.; Reiner, G. Sustainable Global Agrifood Supply Chains: Exploring the Barriers. *J. Ind. Ecol.* **2017**, *21*, 249–260. [CrossRef]
13. Ross, R.B.; Pandey, V.; Ross, K.L. Sustainability and strategy in US agri-food firms: An assessment of current practices. *Int. Food Agribus. Manag. Rev.* **2015**, *18*, 17–47.
14. Barth, H.; Ulvenblad, P.; Ulvenblad, P. Towards a conceptual framework of sustainable business model innovation in the agri-food sector: A systematic literature review. *Sustainability* **2017**, *9*, 1620. [CrossRef]
15. Gómez Orea, D. *Evaluación de Impacto Ambiental: Un Instrumento Preventivo para la Gestión Ambiental*; Mundi-Prensa Libros: Madrid, Spain, 2002; pp. 85–86.
16. Collier, Z.A.; Wang, D.; Vogel, J.T.; Tatham, E.K.; Linkov, I. Sustainable roofing technology under multiple constraints: A decision-analytical approach. *Environ. Syst. Decis.* **2013**, *33*, 261–271. [CrossRef]
17. Aramyan, L.H.; Oude Lansink, A.G.J.M.; van der Vorst, J.G.A.J.; van Kooten, O. Performance measurement in agrifood supply chains a case study. *Supply Chain Manag. Int. J.* **2007**, *12*, 304–315. [CrossRef]

18. Joshi, S.; Singh, R.K.; Sharma, M. Sustainable agri-food supply chain practices: Few empirical evidences from a developing economy. *Glob. Bus. Rev.* **2020**, *24*, 451–474. [CrossRef]
19. Varsei, M.; Soosay, C.; Fahimnia, B.; Sarkis, J. Framing sustainability performance of supply chains with multidimensional indicators. *Supply Chain Manag.* **2014**, *19*, 242–257. [CrossRef]
20. Schäufele, I.; Hamm, U. Consumers' perceptions, preferences and willingness-to-pay for wine with sustainability characteristics: A review. *J. Clean. Prod.* **2017**, *147*, 379–394. [CrossRef]
21. Rondoni, A.; Grasso, S. Consumers behaviour towards carbon footprint labels on food: A review of the literature and discussion of industry implications. *J. Clean. Prod.* **2021**, *301*, 127031. [CrossRef]
22. Liu, G. Food Safety Regulation in Perspective of Environmental Sustainability. In Proceedings of the ICITEE '18: Proceedings of the International Conference on Information Technology and Electrical Engineering, Xiamen, China, 7–8 December 2018; pp. 1–4. [CrossRef]
23. Kumar, A.; Mangla, S.K.; Kumar, P. An integrated literature review on sustainable food supply chains: Exploring research themes and future directions. *Sci. Total Environ.* **2022**, *821*, 153411. [CrossRef]
24. Giuliani, E.; Morrison, A.; Rabellotti, R. *Innovation and Technological Catch-Up: The Changing Geography of Wine Production*; Edward Elgar Publishing: Cheltenham, UK, 2011.
25. Santini, C.; Cavicchi, A.; Casini, L. Sustainability in the wine industry: Key questions and research trendsa. *Agric. Food Econ.* **2013**, *1*, 1–14. [CrossRef]
26. Szolnoki, G. A cross-national comparison of sustainability in the wine industry. *J. Clean. Prod.* **2013**, *53*, 243–251. [CrossRef]
27. Pickering, G.J. Consumer engagement with sustainable wine: An application of the Transtheoretical Model. *Food Res. Int.* **2023**, *174*, 113555. [CrossRef] [PubMed]
28. Gabzdylova, B.; Raffensperger, J.F.; Castka, P. Sustainability in the New Zealand wine industry: Drivers, stakeholders and practices. *J. Clean. Prod.* **2009**, *17*, 992–998. [CrossRef]
29. Marshall, R.S.; Cordano, M.; Silverman, M. Exploring individual and institutional drivers of proactive environmentalism in the US wine industry. *Bus. Strategy Environ.* **2005**, *14*, 92–109. [CrossRef]
30. De Steur, H.; Temmerman, H.; Gellynck, X.; Canavari, M. Drivers, adoption, and evaluation of sustainability practices in Italian wine SMEs. *Bus. Strategy Environ.* **2020**, *29*, 744–762. [CrossRef]
31. Meissenheimer, J.; Karaan, A.; Vink, N. *Sources of Transaction Costs in the South African Wine Supply Chain: Implications for Enhancing Chain Competitiveness*; Department of Agricultural Economics, University of Stellenbosch: Stellenbosch, South Africa, 2001.
32. Goncharuk, A.G. Wine value chains: Challenges and prospects. *J. Appl. Manag. Investig.* **2017**, *6*, 11–27.
33. Luzzani, G.; Lamastra, L.; Valentino, F.; Capri, E. Development and implementation of a qualitative framework for the sustainable management of wine companies. *Sci. Total Environ.* **2021**, *759*, 143462. [CrossRef]
34. OIV Resolution CST 1/2008—OIV Guidelines for Sustainable Vitiviniculture: Production, Processing and Packaging of Products. Available online: https://www.oiv.int/public/medias/2089/cst-1-2008-en.pdf (accessed on 16 May 2023).
35. Kamboj, S.; Gupta, N.; Bandral, J.D.; Gandotra, G.; Anjum, N. Food safety and hygiene: A review. *Int. J. Chem. Stud.* **2020**, *8*, 358–368. [CrossRef]
36. World Health Organization. *Guidance on Regulatory Assessment of HACCP: Report of a Joint FAO/WHO Consultation on the Role of Government Agencies in Assessing HACCP, Geneva, 2–6 June 1998*; WHO: Geneva, Switzerland, 1998.
37. European Commission. *Commission Notice (2022/C 355/01) on the Implementation of Food Safety Management Systems Covering Good Hygiene Practices and Procedures Based on the HACCP Principles, Including the Facilitation/Flexibility of the Implementation in Certain Food Businesses*; 2022/C 355/01; European Commission: Brussels, Belgium, 2022; pp. 1–58.
38. European Commission. Commission Notice on the implementation of food safety management systems covering prerequisite programs (PRPs) and procedures based on the HACCP principles, including the facilitation/flexibility of the implementation in certain food businesses. *OJC* **2016**, *278*, 1–32.
39. Mortimore, S.; Wallace, C. *HACCP: A Practical Approach*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2013.
40. Chen, H.; Liou, B.; Hsu, K.; Chen, C.; Chuang, P. Implementation of food safety management systems that meets ISO 22000:2018 and HACCP: A case study of capsule biotechnology products of chaga mushroom. *J. Food Sci.* **2021**, *86*, 40–54. [CrossRef]
41. Codex Alimentarius Commission Recommended international code of practice general principles of food hygiene. *CAC/RCP Rev.* **2003**, *4*, 1–1969.
42. Christaki, T.; Tzia, C. Quality and safety assurance in winemaking. *Food Control* **2002**, *13*, 503–517. [CrossRef]
43. *ISO 14001:2015*; Environmental Management Systems: Requirements with Guidance for Use. International Organization for Standardization: Geneva, Switzerland, 2015.
44. Gilinsky, A., Jr.; Newton, S.K.; Vega, R.F. Sustainability in the global wine industry: Concepts and cases. *Agric. Agric. Sci. Procedia* **2016**, *8*, 37–49. [CrossRef]
45. Barla, P. ISO 14001 certification and environmental performance in Quebec's pulp and paper industry. *J. Environ. Econ. Manag.* **2007**, *53*, 291–306. [CrossRef]
46. Marimon, F.; Llach, J.; Bernardo, M. Comparative analysis of diffusion of the ISO 14001 standard by sector of activity. *J. Clean. Prod.* **2011**, *19*, 1734–1744. [CrossRef]
47. de Neves, F.O.; Salgado, E.G.; Beijo, L.A. Analysis of the Environmental Management System based on ISO 14001 on the American continent. *J. Environ. Manag.* **2017**, *199*, 251–262. [CrossRef]

48. International Organization for Standardization (ISO). Introduction to ISO 14001:2015. Available online: https://www.iso.org/files/live/sites/isoorg/files/store/en/PUB100371.pdf (accessed on 25 December 2023).
49. Salim, H.K.; Padfield, R.; Hansen, S.B.; Mohamad, S.E.; Yuzir, A.; Syayuti, K.; Tham, M.H.; Papargyropoulou, E. Global trends in environmental management system and ISO14001 research. *J. Clean. Prod.* **2018**, *170*, 645–653. [CrossRef]
50. Summers Raines, S. Implementing ISO 14001—An International Survey Assessing the Benefits of Certification. *Corp. Environ. Strategy* **2002**, *9*, 418–426. [CrossRef]
51. *ISO/TC 207/SC 1*; Environmental Management Systems. International Organization for Standardization: Geneva, Switzerland, 1993.
52. González-Benito, J.; González-Benito, O. An analysis of the relationship between environmental motivations and ISO14001 certification. *Br. J. Manag.* **2005**, *16*, 133–148. [CrossRef]
53. Baiano, A. An overview on sustainability in the wine production chain. *Beverages* **2021**, *7*, 15. [CrossRef]
54. Pomarici, E.; Amato, M.; Vecchio, R. Environmental Friendly Wines: A Consumer Segmentation Study. *Agric. Agric. Sci. Procedia* **2016**, *8*, 534–541. [CrossRef]
55. DeGroot, M.H. *Probability and Statistics*, 2nd ed.; Addison-Wesley: Reading, MA, USA, 2002.
56. Kwak, S.G.; Kim, J.H. Central limit theorem: The cornerstone of modern statistics. *Korean J. Anesthesiol.* **2017**, *70*, 144–156. [CrossRef] [PubMed]
57. López-Santiago, J.; García, A.I.G.; Gómez-Villarino, M.T. An Evaluation of Food Safety Performance in Wineries. *Foods* **2022**, *11*, 1249. [CrossRef]
58. Cloquell-Ballester, V.; Monterde-Díaz, R.; Cloquell-Ballester, V.; Torres-Sibille, A.d.C. Environmental education for small- and medium-sized enterprises: Methodology and e-learning experience in the Valencian region. *J. Environ. Manag.* **2008**, *87*, 507–520. [CrossRef]
59. Campos, L.M.S.; de Melo Heizen, D.A.; Verdinelli, M.A.; Cauchick, M.P.A. Environmental performance indicators: A study on ISO 14001 certified companies. *J. Clean. Prod.* **2015**, *99*, 286–296. [CrossRef]
60. López-Santiago, J.; García, A.I.G.; Villarino, A.G.; Som, A.M.; Gómez-Villarino, M.T. Assessing wineries' performance in managing critical control points for arsenic, lead, and cadmium contamination risk in the wine-making industry: A survey-based analysis utilizing performance indicators as a results tool. *Heliyon* **2024**, *10*, e22962. [CrossRef]
61. Epuran, G.; Bratucu, G.; Bărbulescu, O.U.; Neacşu, N.A.; Madar, A. Food Safety and Sustainability—An Exploratory Approach at the Level of the Romanian Wine Production Companies. *Amfiteatru Econ.* **2018**, *20*, 151–167. [CrossRef]
62. Flores, S.S. What is sustainability in the wine world? A cross-country analysis of wine sustainability frameworks. *J. Clean. Prod.* **2018**, *172*, 2301–2312. [CrossRef]
63. Magan, N. Mycotoxin contamination of food in Europe: Early detection and prevention strategies. *Mycopathologia* **2006**, *162*, 245–253. [CrossRef] [PubMed]
64. Martinez-Rodriguez, A.J.; Carrascosa, A.V. HACCP to control microbial safety hazards during winemaking: Ochratoxin A. *Food Control* **2009**, *20*, 469–475. [CrossRef]
65. Lee, J.C.; Neonaki, M.; Alexopoulos, A.; Varzakas, T. Case Studies of Small-Medium Food Enterprises around the World: Major Constraints and Benefits from the Implementation of Food Safety Management Systems. *Foods* **2023**, *12*, 3218. [CrossRef]
66. Lee, J.C.; Daraba, A.; Voidarou, C.; Rozos, G.; El Enshasy, H.A.; Varzakas, T. Implementation of Food Safety Management Systems along with Other Management Tools (HAZOP, FMEA, Ishikawa, Pareto). The Case Study of Listeria monocytogenes and Correlation with Microbiological Criteria. *Foods* **2021**, *10*, 2169. [CrossRef]
67. Zhang, L.; Ye, F.; Yang, L.; Zhou, G. Impact of political connections on corporate environmental performance: From a green development perspective. *Sustainability* **2019**, *11*, 1317. [CrossRef]
68. Laca, A.; Gancedo, S.; Laca, A.; Díaz, M. Assessment of the environmental impacts associated with vineyards and winemaking. A case study in mountain areas. *Environ. Sci. Pollut. Res.* **2021**, *28*, 1204–1223. [CrossRef]
69. Iannone, R.; Miranda, S.; Riemma, S.; De Marco, I. Improving environmental performances in wine production by a life cycle assessment analysis. *J. Clean. Prod.* **2016**, *111*, 172–180. [CrossRef]
70. Fiore, M.; Giacomarra, M.; Crescimanno, M.; Galati, A. Quality certifications' impact on wine industry assets performance. *Bulg. J. Agric. Sci.* **2020**, *26*, 257–267.
71. Giacomarra, M.; Galati, A.; Crescimanno, M.; Tinervia, S. The integration of quality and safety concerns in the wine industry: The role of third-party voluntary certifications. *J. Clean. Prod.* **2016**, *112*, 267–274. [CrossRef]
72. Carrillo-Higueras, F.; Prajogo, D.; Smith, L. Environmental commitment and its drivers in the Australian wine industry: A behavioural approach. *Australas. J. Environ. Manag.* **2018**, *25*, 439–458. [CrossRef]
73. Gierling, F.; Blanke, M. Carbon reduction strategies for regionally produced and consumed wine: From farm to fork. *J. Environ. Manag.* **2021**, *278*, 111453. [CrossRef]
74. Carroquino, J.; Garcia-Casarejos, N.; Gargallo, P. Classification of Spanish wineries according to their adoption of measures against climate change. *J. Clean. Prod.* **2020**, *244*, 118874. [CrossRef]

4.6 Summary scheme of the Results

The summary of the results obtained in the research is presented by **Table 9.**

Table 9: Research results summary

<table>
<tr><th>Article</th><th>Objective</th><th>Key Findings</th></tr>
<tr>
<td>Evaluation of Food Safety Performance in Wineries. Foods, 11(9), 1249. 2022
<table>
<tr><td>CATEGORY: FOOD SCIENCE & TECHNOLOGY</td><td>SCIE</td></tr>
<tr><td>JCR YEAR</td><td>2022</td></tr>
<tr><td>JIF RANK</td><td>34/142</td></tr>
<tr><td>JIF QUARTILE</td><td>Q1</td></tr>
<tr><td>JIF PERCENTILE</td><td>76.4</td></tr>
<tr><td>CITATION</td><td>6</td></tr>
<tr><td>Published</td><td>MAY 2022</td></tr>
</table>
</td>
<td>SO-1.- Analyse and evaluate the FS management in promoting the sustainability of the wine production.</td>
<td>

PRPs Implementation: 91.5% of wineries implemented, with a focus on larger production scales.
Worker Training: 81% of wineries have >50% workforce trained in GMP, especially notable in wineries >100,000 L/year.
Knowledge and Budgeting: 95% of wineries report significant workforce knowledge on PRPs; 62% formulate PRPs without a specific budget; larger wineries maintain dedicated budgets.
HACCP Adoption: 76.2% of wineries have embraced HACCP, with varying control over CCPs.

</td>
</tr>
<tr>
<td>Assessing wineries' performance in managing critical control points for arsenic, lead, and cadmium contamination risk in the wine-making industry: A survey-based analysis utilizing performance indicators as a results tool. Heliyon, 10(1). JAN 15 20242024
<table>
<tr><td>CATEGORY: MULTIDISCIPLINARY SCIENCES</td><td>SCIE</td></tr>
<tr><td>JCR YEAR</td><td>2022</td></tr>
<tr><td>JIF RANK</td><td>23/73</td></tr>
<tr><td>JIF QUARTILE</td><td>Q2</td></tr>
<tr><td>JIF PERCENTILE</td><td>69.2</td></tr>
<tr><td>CITATION</td><td>1</td></tr>
<tr><td>Published</td><td>JAN 2024</td></tr>
</table>
</td>
<td>SO-3.- Identify and analyse key components of sustainability in the wineries based on FS management and EM performance.</td>
<td>

Regulation Adherence: 96.9% follow regulations with significant training in GMP and CCPs; 93.8% meet standards.
Training Correlation: Positive link between GMP and CCP training.
Legislative Awareness: Smaller wineries show less awareness; gap in using AESAN resources.
Quantitative measure method:
Performance Indicators for training, compliance, and chemical analysis: I_{FSWT}, I_{LIU}, $I_{CCP-MCHEM}$.

</td>
</tr>
</table>

<table>
<tr><th>Article</th><th>Objective</th><th>Key Findings</th></tr>
<tr>
<td>An Evaluation of Sustainability in Wineries Based on Their Performance in Compliance with Food Safety". In Proceedings of the 12th Iberian Agroengineering Congress. XII Congreso Ibérico de Agroingeniería. (2023) Junta de Andalucía: Sevilla - Spain.</td>
<td>SO-3.- Identify and analyse key components of sustainability in the wineries based on FS management and EM performance.</td>
<td>

Contamination Risks: Notable deficiencies in managing trace metal and biological hazards.
Proposals: Performance indicators for training, compliance, and analysis to improve FS.

</td>
</tr>
<tr>
<td>Assessment of Environmental Management Performance in Wineries: A Survey-Based Analysis to create Key Performance Indicators. Environments 2024.
<table>
<tr><td>CATEGORY: ENVIRONMENTAL SCIENCES</td><td>ESCI</td></tr>
<tr><td>JCR YEAR</td><td>2022</td></tr>
<tr><td>JIF RANK</td><td>190/334</td></tr>
<tr><td>JIF QUARTILE</td><td>Q3</td></tr>
<tr><td>JIF PERCENTILE</td><td>43.26</td></tr>
<tr><td>CITATION</td><td>0</td></tr>
<tr><td>Published</td><td>UNDER PEER REVIEW 18/04/24</td></tr>
</table>
</td>
<td>SO-2.- Analyse and evaluate the EM performance in promoting the sustainability of the wine production.

SO-3.- Identify and analyse key components of sustainability in the wineries based on FS management and EM performance.</td>
<td>

EM Areas Focus: Large wineries (80%) show structured EM focus.
Communication: Email (74.2%) and social media (84.4%) dominate for internal and external communications, respectively.
Workforce and EM Focus: Most wineries employ fewer than ten workers.
Environmental Policies and Leadership: 71.9% of wineries have established environmental policies.
Quantitative measure method:
Performance Indicators for environmental communication, commitment, planning, management requirements, and training: I_{ecm}, I_{ecx}, I_{epx}, I_{erx}, I_{ewt} .

</td>
</tr>
<tr>
<td>Exploring Sustainability in Wineries: Evaluating Food Safety and Environmental Management Aligning with the Farm to Fork Strategy. Agriculture 2024, 14, 330.
<table>
<tr><td>CATEGORY: AGRONOMY</td><td>SCIE</td></tr>
<tr><td>JCR YEAR</td><td>2022</td></tr>
<tr><td>JIF RANK</td><td>17/88</td></tr>
<tr><td>JIF QUARTILE</td><td>Q1</td></tr>
<tr><td>JIF PERCENTILE</td><td>81.3</td></tr>
<tr><td>CITATION</td><td>0</td></tr>
<tr><td>Published</td><td>MAR 2024</td></tr>
</table>
</td>
<td>SO-4.- Design a tool to measure progress of sustainability and test it.</td>
<td>

Sustainability Matrix (SM): Synthesis of three research studies and proposal of the SM as a tool for assessing wineries performance in FM and EM towards to measure their sustainability practices progress, featuring color-coded indicator values.

</td>
</tr>
</table>

4.7 Key Takeaways

These key takeaways highlight crucial aspects of ensuring success and sustainability in the winery industry:

- **Effective Implementation:** The success of PRPs and HACCP relies heavily on worker training, knowledge, and proper budget allocation. Ensuring that employees are well-trained and adequately equipped with the necessary resources is essential for these programs to function effectively.
- **Risk Management:** Continuous improvement is vital for managing contamination risks and ensuring compliance with regulations. Wineries must remain vigilant and consistently update their processes to mitigate risks and maintain regulatory standards.
- **Structured EM Efforts:** Larger wineries tend to exhibit more systematic environmental management practices. Effective communication strategies play a significant role in ensuring the successful implementation of these practices throughout the organization.
- **Quantitative Sustainability Assessment:** The introduction of the SM provides wineries with a comprehensive tool for measuring their sustainability efforts. This quantitative approach allows wineries to assess their sustainability performance across various dimensions and identify areas for improvement.

5 Discussion

In the backdrop of a global concern for the sustainability of agricultural and food production, the EU stands as a focal point. As reported by the European Commission, food production within the EU continues to have an adverse impact on the environment, necessitating a shift towards sustainability principles that seamlessly integrate environmental preservation, FS, and nutritious sustenance (European Commission, 2020c).

Wine production methods must evolve to align with sustainability objectives. The integration of sustainability in wine production industry requires methodical approaches, considering the complex challenges and opportunities. FS assurance, responsible agricultural practices and reduction of environmental impacts emerge as pivotal strategies for wineries (Epuran, Bratucu, Bărbulescu, Neacşu, & Madar, 2018; Flores, 2018).

This chapter seeks to synthesize findings from the research focused on EMS and FSMS within the wine production industry. By examining how EMS and FSMS impact sustainability outcomes, the research has delved into the influence of winery size on the effectiveness of these systems and explores the roles of training, leadership, and legislative compliance in enhancing implementation, and other environmental components represented by each environmental performance indicators.

5.1 Interconnections between FS and EM

Understanding the interconnections between FS and EM within wineries is critical for achieving comprehensive winemaking sustainable practices. The research provides a foundation to explore these links, highlighting how practices in one area can influence outcomes in another.

FS and EM often share common practices that aim to ensure product quality while minimizing negative environmental impacts. For example, the management of chemical inputs, such as pesticides and fungicides, is crucial for both preventing contamination of wine (a food safety concern) and reducing soil and water pollution (an environmental concern). Control of metal contaminants like Cadmium, Lead, and Arsenic in grapes is often insufficient, posing risks not only to consumer health but also to environmental integrity wine (Christaki & Tzia, 2002; Magan, 2006; Martinez-Rodriguez & Carrascosa, 2009).

EM practices can have a direct impact on FS outcomes. For instance, sustainable water management practices not only conserve water resources but also reduce the risk of waterborne contaminants affecting the vineyard and, subsequently, the wine production process. Osborne (2022) highlighted those wineries that implemented rigorous water quality monitoring and treatment systems reported fewer issues with microbial contamination, a key aspect of FS (Osborne, 2022).

Conversely, stringent FS protocols can influence environmental health. Practices such as the proper handling and disposal of waste from wine production, like grape skins and seeds, can prevent environmental contamination. Furthermore, the reduction of chemical additives in wine production not only addresses consumer safety concerns but also reduces the chemical load discharged into the environment. These findings are similar to other studies focusing on controlling microbiologic contamination in wines that have also demonstrated as a significant contributing factor to prevent contamination (Martinez-Rodriguez & Carrascosa, 2009).

5.1.1 Performance variability by winery size

It is evident that larger wineries exhibit a more robust implementation of FSMS, such as HACCP. Findings noted that larger wineries are more likely to have fully implemented PPRs and CCPs. In contrast, smaller wineries often face challenges with these implementations due to limited resources and less formalized training programs. Results indicated that while over 90% of larger wineries had a complete HACCP plan in place, only about 75% of smaller wineries had reached a similar level of implementation.

Environmental management presents a similar trend. Larger wineries are more likely to adopt comprehensive EMS practices, facilitated by greater financial and human resources. These wineries often achieve higher compliance with regulations pertaining to waste management, energy use, and water conservation. Smaller wineries, however, tend to have less structured approaches, partly due to a lack of expertise and funding to invest in necessary technologies and practices. The data revealed that large wineries reported nearly 85% compliance with ISO 14001 environmental standards, whereas smaller wineries reported only about 50% compliance. Besides, results reveal that the significance of ISO 14001:2015 certification is low, in line with other studies conducted in the Italian wine sector (Fiore, Giacomarra, Crescimanno, & Galati, 2020; Giacomarra, Galati, Crescimanno, & Tinervia, 2016).

Findings across the studies illustrate that larger wineries show higher compliance with EMS and FSMS, attributed to better resources and structured management practices. Conversely, smaller wineries often struggle with these aspects due to resource constraints. This indicates a critical need for policy interventions that support smaller wineries through subsidies, training, and access to technology to enhance their sustainability performance.

The performance of wineries in implementing winemaking sustainable practices and adhering to environmental and FS standards varies significantly with size. The analysis demonstrates a clear divide in how different sized wineries manage their operational, safety, and environmental challenges.

Another significant factor influencing performance across winery sizes is the adoption of technology. Larger wineries are more likely to invest in advanced technologies for monitoring and improving FS and environmental impacts. This includes everything from chemical analysis systems to environmental operation control processes. Smaller wineries, due to budget constraints, often lag in this area, which can hinder their ability to effectively monitor and manage environmental and safety risks.

5.1.2 Performance in environmentally sustainable objectives

Environmental objectives such as waste, electricity, and water reduction are central to the sustainability goals of wineries. However, inconsistencies in how these objectives are prioritized and implemented, particularly in relation to reducing fossil fuel consumption and enhancing emergency preparedness. These gaps present opportunities for wineries to adopt more integrated and strategic approaches to sustainability, which could include better alignment of annual targets with long-term environmental commitments. These findings are aligned with other studies about environmental aspects and impacts in winemaking process and the measures to reduce them (Iannone, Miranda, Riemma, & De Marco, 2016; Laca, Gancedo, Laca, & Díaz, 2021; Zhang, Ye, Yang, & Zhou, 2019).

5.2 Deep dive into Training, Leadership, and Legislative Compliance

5.2.1 Training

The linkage between FS and EM is further reinforced through training. Wineries that provide comprehensive training programs covering both domains tend to have staff who are better equipped to manage complex situations that may impact both FS and EM. The research pointed out that wineries investing in continuous professional development in these areas often achieve higher standards of compliance and innovation in sustainable practices. These findings are consistent with the research conducted by Lee, J.C. et al (Lee, J. C., Neonaki, Alexopoulos, & Varzakas, 2023; Lee, J. C. et al., 2021), wherein the importance of aspects related to FS culture is underscored, particularly about human factors and specialized training.

Effective EMS and FS protocols rely heavily on robust training programs. The disparity in training levels, particularly between larger and smaller wineries, directly affects the success of these systems. Training enhances operator understanding and compliance, which are crucial for the effective functioning of these protocols. The research offers a comprehensive view of the current state and disparities in training practices across wineries of varied sizes and regions. Larger wineries typically have more structured training programs that are regularly updated to comply with new regulations and standards. In contrast, smaller wineries often rely on informal or occasional training sessions, which may not cover all critical aspects of food safety and environmental management. Results show a significant correlation between the extent of training and the effectiveness of EMS and FSMS, particularly noting that wineries with more comprehensive training regimes showed better overall performance in sustainability metrics.

An overview of current FS training practices indicates that while most large wineries have established robust training programs in FS, including the implementation of HACCP systems, smaller wineries often exhibit gaps. The results indicate that smaller wineries face significant challenges in complying with HACCP standards, primarily due to inadequate training and limited resources. This aligns with findings by Yapp (2006), who noted that knowledge of the basic principles of FS and its requirements tends to be low among small and medium-sized agrifood businesses. (Yapp & Fairman, 2006). Only a fraction of smaller wineries had fully trained staff, significantly impacting their ability to monitor and control critical safety points.

The effectiveness of training programs varies significantly, not just by winery size but also by the specific safety protocols being implemented. For example, training on chemical safety, such as the management of pesticides and fungicides, tends to be less comprehensive across the board. This discrepancy can lead to inconsistencies in the application of safety measures, particularly in critical areas such as the control of trace metals and microbiological hazards in wines. These observations align with previous research studies by Chaudhary (Chaudhary, 2020) and Saeed (Saeed et al., 2019), highlighting a congruence in the identified training trends across other investigations.

Several studies underscore the barriers to effective training, including limited financial resources, lack of specialized trainers, and the transient nature of agricultural labour (Aivazidou & Tsolakis, 2020; Ghezzi, Ayoun, & Lee, 2021; Mthombeni, Antwi, & Oduniyi, 2022). Additionally, the linguistic diversity within the EU poses challenges in delivering uniform training content across member states, complicating the dissemination of best practices (Tenzer, Pudelko, & Zellmer-Bruhn, 2021).

EM training is less uniform than FS training across wineries. Larger wineries, due to their greater operational scales and often more stringent regulatory scrutiny, tend to have more structured environmental training programs. These programs frequently cover topics such as waste management, energy conservation, and water usage reduction. In contrast, smaller wineries may not have formal training programs, relying instead on ad-hoc practices that can lead to less effective environmental management.

The direct impact of training on achieving sustainability goals is evident in larger wineries that align their training programs with their EMS. These wineries typically demonstrate better performance in sustainability metrics, as they are more likely to integrate advanced technologies and practices learned through formal training into their daily operations. However, the lack of such structured training in smaller wineries often results in poorer compliance with environmental standards and less effective implementation of EMS. These findings are aligned with the research results of the environmental initiatives between small and large wineries achieved by Knowles (2001) (Knowles & Hill, 2001).

Improving training in environmental management across all wineries is crucial. This involves not only increasing the availability and accessibility of training programs but also ensuring that they are tailored to the specific needs and capacities of wineries of varied sizes. Leveraging EU funding and support, collaborative training initiatives can be developed that utilize online platforms to overcome geographical and linguistic barriers, providing standardized, high-quality training across the region.

The comparative analysis reveals significant disparities in the training for FS and EM across wineries, particularly between larger and smaller establishments. To bridge these gaps, there is a pressing need for standardized, accessible, and comprehensive training programs that are supported at the EU level. This approach would ensure that all wineries, regardless of size or location, have the knowledge and skills necessary to implement effective FS measures and EM practices.

5.2.2 Leadership role

Effective leadership is crucial for fostering a culture of safety and environmental responsibility. Leaders in larger wineries typically drive proactive involvement in environmental initiatives, ensuring compliance with international standards. In smaller wineries, leadership often involves direct engagement with all staff levels, promoting an integrated approach to EM and FS.

Chen (2020) found that the active commitment of senior management to the efficacy of FSMS and EMS sets a precedence that permeates throughout the business. This commitment ensures that all levels of the organization are aligned, which simplifies the integration of safety standards into daily operations and helps in achieving broader sustainability targets (Chen et al., 2020).

Results indicate that wineries led by management teams who are deeply committed to environmental and safety standards show improved compliance and better overall performance. These wineries often implement comprehensive training programs and regularly evaluate their processes to ensure they are in line with or exceed regulatory requirements.

The empirical evidence suggests that wineries with an important level of leadership commitment see enhanced operational efficiencies and adherence to safety protocols. Training initiatives that are well-supported by the leadership tend to be more thorough and effective, covering crucial aspects from chemical safety to waste management. These training programs are essential for ensuring that the staff understands and can effectively implement necessary safety and sustainability practices.

Leadership in wineries also extends to fostering an initiative-taking approach towards training and development. Effective leaders recognize the importance of continuous learning and adaptation, particularly in an industry where production processes are closely intertwined with environmental impact and public health concerns (Pomarici, Corsi, Mazzarino, & Sardone, 2021).

The effectiveness of FS and EM within wineries hinges significantly on the role of committed leadership. Leaders who embody and advocate for these principles promote a culture of sustainability that is essential for the long-term success of their operations.

5.2.3 Compliance challenges across winery sizes

Larger wineries typically have the resources to navigate these complex regulatory environments more effectively. They often employ compliance officers whose sole responsibility is to ensure that all aspects of the winery operations adhere to local and international laws. These wineries also tend to have more structured approaches to compliance, with regular audits and reviews to ensure that all practices are up to date with current laws. The ability to invest in sophisticated compliance software and systems further aids these wineries in maintaining ambitious standards.

Conversely, smaller wineries often struggle with regulatory compliance due to limited resources. The cost of maintaining up-to-date knowledge of all applicable regulations and implementing necessary changes can be prohibitive. Smaller wineries may lack the personnel necessary to dedicate to compliance, often requiring staff to manage multiple roles, which can dilute the focus on regulatory adherence. These results match with the alcoholic beverage industry´s weakness in compliance with FS legislation demonstrated by Kourtis L.K. (Kourtis & Arvanitoyannis, 2001). Enhancing legislative knowledge and application across the industry, particularly among smaller wineries, is crucial for maintaining ambitious standards of safety and environmental care. Small wineries benefit from simplified regulations or support from external organizations that can provide guidance and assistance in meeting compliance requirements.

Also, it is important to consider the role of training in enhancing compliance. Effective training programs are essential for ensuring that all winery staff, regardless of the size of the business, understand the regulations that impact their operations and how to comply with them. Training that specifically addresses compliance can help prevent violations that may lead to fines, legal issues, or damage to the winery reputation.

Given the resource disparities between large and small wineries, targeted support policies are essential. Financial incentives for sustainability investments, training subsidies, and accessible guidance on legislative compliance could significantly enhance the capability of smaller wineries to implement effective EMS and FSMS. These outcomes are in accordance with the findings of Szolnoki, G. (Szolnoki, 2013) who highlighted the pros and cons of sustainable wine production.

5.3 Beyond traditional metrics about sustainable practices in wineries

Incorporating broader metrics that measure environmental and health risks impacts is recommended to provide a more comprehensive view toward the sustainability in wine production. The SM serves as both a diagnostic tool and a strategic guide, enabling wineries to identify areas of strength and opportunities for improvement regarding FS and EM to be wineries more sustainable. By quantifying performance across two dimensions of wine production sustainability, it facilitates targeted interventions and fosters continuous improvement towards achieving higher standards of sustainability aligned with the Farm to Fork Strategy. As such, this matrix is not merely a summary of past performance but a forward-looking instrument that empowers wineries to evolve their practices in line with emerging sustainability trends and regulatory demands.

5.3.1 Application of the SM in Policy Design

The SM can help policymakers understand where wineries are in their sustainability journey. By analysing the data collected through the matrix, policymakers can identify common areas where wineries struggle, such as waste management or energy efficiency, and design targeted support programs to address these issues. For instance, if the SM reveals that a substantial number of small to medium-sized wineries have deficient performance in energy efficiency, policies could be designed to provide subsidies or tax incentives for energy-saving equipment.

The SM provides a mechanism for continuous monitoring and reporting of sustainable practices outcomes in FS and EM. This feature is invaluable for tracking the effectiveness of implemented policies and making necessary adjustments. Policies that aim to improve specific sustainability metrics can be monitored through periodic reviews using the matrix, ensuring that these policies are achieving their intended outcomes and contributing positively to the overall sustainability of the industry.

By establishing benchmarks for sustainability performance, the SM helps in setting clear and achievable standards for wineries. Policymakers can use these benchmarks to define compliance thresholds for regulatory purposes or to incentivize higher levels of sustainability achievement based on FS and EM. For example, wineries that consistently perform above the benchmark in the SM could be rewarded with certifications or public recognition, encouraging a competitive spirit towards sustainable winemaking practices among industry players.

The SM fosters transparency and facilitates stakeholder engagement by providing a clear and objective assessment of wineries sustainable winemaking practices performance.

Policymakers can use this tool to engage with various stakeholders, including winery owners, environmental groups, and the local community, to discuss and refine sustainability initiatives. This engagement ensures that the policies are well-rounded and effectively address the concerns and needs of all stakeholders involved.

The insights gained from the SM can guide research and development efforts towards sustainable practices in the wine industry. Policies can be developed to support Research & Development (R&D) in areas where there are significant gaps in technology or practices, as identified by the matrix. Supporting innovation through R&D grants or partnerships with academic institutions can lead to advancements in sustainable practices that can be widely adopted within the industry.

In summary, the evaluation of FS and EM practices in wineries towards improving their sustainability, which relies heavily on a set of eight performance indicators encompassed within the SM, reveals a comprehensive picture. The combined results, irrespective of the production levels of the wineries, categorize their status of wineries in terms of FS and EM as "In Progress." This designation highlights substantial opportunities for further improvement, particularly in areas such as legal requirements, chemical analysis, environmental communication, environmental planning, and other environmental requirements. These findings are consistent with those presented by Szolnoki (2013), who noted similar trends in sustainable practices within the industry (Szolnoki, 2013). Additionally, these observations align well with the research conducted by Baiano (2021), further validating the widespread recognition of the need for ongoing enhancements in winery sustainability practices (Baiano, 2021).

5.4 Limitation and strength of the thesis

One of the key drawbacks of the thesis resides in the diminished rate of participation received from the wineries under examination, which could potentially influence the inclusiveness and applicability of the data to the broader wine industry. Nonetheless, a fundamental merit of this study is grounded in the formulation of performance metrics utilizing the questionnaire approach. This instrument establishes a sturdy groundwork for scrutinizing data and facilitates the assessment of wineries' performance in FSMS and EMS focus in their sustainability.

6 Conclusion

The **hypothesis** has been confirmed showing that the progress towards sustainability of wine production is related with the implementation level of FSMS and EMS based on HACCP and ISO 14001:2015 standards in wineries. A higher level of performance in FSMS and EMS is associated with improved behaviours in sustainable practices in wineries. The findings have demonstrated that high performance in FSMS reduces health risks for wine consumers and ensures compliance with FS standards. Similarly, high performance in EMS significantly helps to minimize the environmental impacts of wine production and underscores a commitment to adhering to environmental legislation. Moreover, it has been established that clear leadership in environmental and FS management at the top level encourages practices that support sustainability.

The **first specific objective (SO-1)**, which pertains to evaluating the development of FS, has been addressed. The thesis highlights the critical need for ongoing improvement in the technical application of the HACCP methodology, as well as the necessity for comprehensive training in FS for winery staff. Identified barriers suggest that creating new formats for CCPs surveillance, which involve a range of professionals within wineries, could improve CCPs monitoring and, in turn, enhance the overall implementation of HACCP. The importance of having motivated, satisfied, and well-trained personnel becomes clear in ensuring the effectiveness of the HACCP.

A proficient implementation of PRPs and HACCP is pivotal in eliminating FS risks, emphasizing the necessity for wineries to enhance hazard identification, analysis, and evaluation. This necessitates improvements in chemical and microbiological analysis laboratories and substantial investments in training and sensitization of all staff. Leadership, demonstrated by winery owners and managers, is identified as crucial for fostering a robust safety culture, facilitating alignment with senior management, and ensuring the effectiveness of FS systems.

Moreover, the thesis reveals that although most wineries have FSMS, there is room for improvement in the identification and control of CCPs related to the contamination risks of arsenic, cadmium, and lead. Wineries must exert adequate control over these risks by staying informed about and adhering to European legislation. Training winery workers in

GMP and CCPs control is identified as a success factor in preventing contamination by these metals.

Despite the high training level of workers in controlling the risk of arsenic, cadmium, and lead contamination, deficiencies persist in the wineries' performance regarding the identification of applicable legislation related to heavy metal contamination risk. The lack of information on contamination sources in grapes, coupled with barriers such as the absence of spectrometry equipment in winery laboratories, presents challenges. Providing wineries with the necessary equipment and resources for chemical analyses could mitigate these challenges and enhance the control of contamination risks associated with heavy metals and metalloids.

The **second specific objective (SO-2)**, which involves evaluating EM performance in the wine industry by analysing the implementation of EMS according to the international standard ISO 14001:2015 and its role as a tool for assessing sustainability in wineries, has been achieved. The thesis provides a comprehensive understanding of EM practices, communication strategies, and the degree of commitment among Italian wineries. It highlights both strengths and areas for improvement in their environmental sustainability efforts, offering valuable insights into the varied approaches and levels of commitment within the industry.

The **third specific objective (SO-3)** has been proved**.** Integrating FS and EM systems offers substantial synergistic benefits by ensuring that wineries operations are both safe for consumers and environmentally sustainable. This integrated approach promotes a more efficient use of resources, reduces operational redundancies, and enhances compliance with both FS and environmental regulations. However, this integration is not without challenges, particularly for smaller wineries. The complexity and cost of implementing can be prohibitive, requiring substantial investment in technology and training.

Besides, there are barriers to effective implementation and variability among wineries. The effective implementation of FS and EM practices varies significantly among wineries, primarily influenced by their size and resources. Larger wineries often have the capital to invest in sophisticated systems and continuous employee training, enabling them to lead in compliance and innovation. In contrast, smaller wineries face significant barriers, including limited financial resources, lack of specialized equipment such as spectrometry for chemical analysis, and challenges in staying updated with relevant legislation. These factors hinder their ability to effectively manage risks associated with contaminants like heavy metals.

Training, particularly in GMP and CCP control, emerges as a critical success factor in managing these risks. Despite the elevated level of training on specific hazards, there is often a lack of comprehensive understanding of applicable legislation and the broader implications of contamination, which are crucial for maintaining high standards of FS.

Leadership plays a crucial role in establishing a strong culture towards sustainability within wineries, where owners and managers must lead by example, showing unwavering commitment to the effectiveness of FSMS and EMS. This dedication not only fosters an environment where all workers feel motivated to align with the objectives of senior management but also facilitates the identification of strengths and areas susceptible to improvement. By doing so, it enriches the perspective on the various approaches adopted by the industry and the level of commitment to sustainability, which is vital for promoting safer and more sustainable practices in the wine sector.

To support wineries in overcoming these challenges and to foster a more robust sustainability culture, targeted policy interventions are necessary. These could include financial and technical support to provide subsidies or low-interest loans to assist smaller wineries in purchasing necessary equipment and technology for FS and EM. Simplified regulatory framework to make compliance more manageable for small and medium-sized enterprises, with clear guidelines and checklists. Enhanced Training Programs through developing and funding comprehensive training initiatives that address both FS and EM, tailored to the needs of wineries of varied sizes. And finally, collaborative efforts, encouraging collaboration among wineries, research institutions, and government agencies to share best practices and innovations in sustainability.

In response to the pressing need for sustainable practices within the EU winery sector, several recommendations have been put forth to bolster both environmental stewardship and FS. These recommendations are designed to be actionable and sustainable, addressing the needs of wineries of varying sizes and capabilities.

Firstly, the implementation of EU-wide training initiatives is crucial. These programs should be meticulously tailored to the needs of wineries of varied sizes, focusing on crucial aspects of sustainability and safety. The development of a standardized training curriculum that addresses both FS and EM, available in multiple languages, is essential for achieving uniformity in training quality across the EU. This standardization would ensure that all winery personnel, regardless of location, receive the same foundational knowledge and updates on best practices. Additionally, increasing EU funding and support for these training initiatives, particularly through the integration of digital platforms, would enhance accessibility and enable broader participation across member states. To ensure these training efforts are effective and evolve with industry needs, establishing a framework for monitoring and evaluating their effectiveness is necessary. This framework would help in continuously improving the training programs and ensuring they align with the changing dynamics of the wine industry.

Strengthening regulatory compliance is another pivotal recommendation. Enhancing enforcement mechanisms to ensure stricter adherence to environmental and food safety regulations would mitigate risks and ensure all operations meet baseline safety and sustainability standards. Supporting this enhancement, initiatives such as subsidizing compliance software could assist smaller wineries in managing their regulatory responsibilities more effectively. Additionally, offering tax incentives for wineries that consistently meet or exceed compliance standards could foster a culture of compliance and excellence.

Comprehensive sustainability planning is also recommended. Wineries should be encouraged to integrate broader sustainability goals into their operational strategies. This integration would promote alignment between short-term actions and long-term environmental objectives, ensuring that sustainability becomes a core aspect of operational planning and not just a peripheral activity.

For smaller wineries, which often face greater challenges due to resource constraints, enhancing EU support is vital. This support could come in the form of grants, subsidies, and technology-sharing initiatives that make sustainable practices more accessible. Capacity-building programs focused on training, resource sharing, and collaborative opportunities are particularly beneficial for these smaller entities. Facilitating access to affordable technology solutions can also play a crucial role in helping these wineries enhance their sustainability and safety performance.

Encouraging the adoption or development of integrated certification programs that address both FS and EM can further bolster sustainable practices. These certification programs would serve as a benchmark for best practices and encourage wineries to meet higher standards.

Support for research and development into best practices and technologies that effectively integrate FS and EM is also critical. This support would ensure that the winery industry remains at the forefront of sustainability practices. Additionally, promoting stakeholder engagement across the industry is essential for fostering knowledge sharing and collaboration on integrated management practices.

Developing partnerships between government bodies and winery associations to facilitate ongoing education and training on regulatory changes is key. Creating a centralized portal for EU winery regulations would simplify the process of staying informed about current and upcoming legislation, aiding wineries in maintaining compliance with ease.

Finally, the **fourth objective (SO-4)** has been achieved. The journey toward sustainability in the EU winery sector, guided by the F2F Strategy, requires a comprehensive approach that integrates FS and EM. By addressing the existing challenges and leveraging the synergies between FS and EM, wineries can enhance their sustainability performance, contributing positively to the broader goals of environmental conservation and food security. The ongoing development of tools like the SM, that is composed of the performance indicators of wineries in different components of sustainability in terms of FS and EM, and supportive policies will be crucial in measuring progress and incentivizing further improvements, ensuring the wine industry's alignment with the evolving demands of consumers, regulators, and the global market for sustainable practices.

7 Future research

Finally, there is many opportunities to further study and delve into the methodology of indicators calculation and its application to other sectors within the agroindustry. The SM, currently utilized to assess FS and EM practices in wineries, provides a robust framework that could be significantly enhanced by the inclusion of additional performance indicators. By incorporating measures from economic, labour, and social domains, this tool could evolve into a comprehensive tool for globally measuring the concept of sustainability in wineries. This expanded approach would allow not only for the assessment of environmental and safety impacts but also for an understanding of how winery operations affect and contribute to the economic and social well-being of their employees and local communities. Consequently, the SM would become an essential instrument for winery managers aiming to optimize their practices towards a truly sustainable business tool across all dimensions. This potential for expansion suggests future research ways. Scholars and industry experts could explore the development of these additional indicators and evaluate their applicability and effectiveness within the matrix. Such research could provide valuable insights into the comprehensive impacts of winery operations, leading to more informed and strategic decision-making in pursuit of sustainability. Besides, the application of artificial intelligence (AI) based on machine learning and neural networks emerges as a promising approach. These techniques have the capability to enhance existing indicators by incorporating new attributes, aiming to facilitate the prediction of sustainability. This process involves expanding predictive capacity through the identification and evaluation of additional factors that impact sustainability in this specific context. The deployment of these advanced methodologies opens the door to a deeper and more precise understanding of sustainable aspects in the operations of wineries and other agro-industrial entities, thereby providing a more comprehensive and anticipatory approach to sustainability management in these sectors.

References

Aivazidou, E., & Tsolakis, N. (2020). A water footprint review of Italian wine: Drivers, barriers, and practices for sustainable stewardship. *Water, 12*(2), 369.

Anderson, K., Nelgen, S., & Pinilla, V. (2017). *Global wine markets, 1860 to 2016: A statistical compendium* University of Adelaide Press.

Ascoli, D., Plana, E., Oggioni, S. D., Tomao, A., Colonico, M., Corona, P., Kaoukis, K. (2023). Fire-smart solutions for sustainable wildfire risk prevention: Bottom-up initiatives meet top-down policies under EU green deal. *International Journal of Disaster Risk Reduction, 92*, 103715.

Baiano, A. (2021). An overview on sustainability in the wine production chain. *Beverages, 7*(1), 15.

Barla, P. (2007). ISO 14001 certification and environmental performance in quebec's pulp and paper industry. *Journal of Environmental Economics and Management, 53*(3), 291-306. doi:10.1016/j.jeem.2006.10.004

Billen, G., Aguilera, E., Einarsson, R., Garnier, J., Gingrich, S., Grizzetti, B., Sanz-Cobena, A. (2024). Beyond the farm to fork strategy: Methodology for designing a European agro-ecological future. *Science of the Total Environment, 908*, 168160.

Bisht, N., & Chauhan, P. S. (2020). Excessive and disproportionate use of chemicals cause soil contamination and nutritional stress. *Soil Contamination-Threats and Sustainable Solutions, 2020*, 1-10.

Chen, H., Liu, S., Chen, Y., Chen, C., Yang, H., & Chen, Y. (2020). Food safety management systems based on ISO 22000: 2018 methodology of hazard analysis compared to ISO 22000: 2005. *Accreditation and Quality Assurance, 25*, 23-37.

Comité Européen des Entreprises Vins, – CEEV. (2024). Economic, social, and environmental importance of the wine sector in the EU. Brussels: Belgium: Comité Européen des Entreprises Vins – CEEV. Retrieved from https://www.ceev.eu/

Council of the European Union (2020). *Council Regulation (EU) 2020/2094 of 14 December 2020 establishing a European Union recovery instrument to support the recovery in the aftermath of the COVID-19 crisis*. Brussels: European Union.

Delmas, M. A., & Gergaud, O. (2021). Sustainable practices and product quality: Is there value in eco-label certification? the case of wine. *Ecological Economics, 183*, 106953.

Delzeit, R., Zabel, F., Meyer, C., & Václavík, T. (2017). Addressing future trade-offs between biodiversity and cropland expansion to improve food security. *Regional Environmental Change, 17*, 1429-1441.

Dhuldhaj, U. P., Singh, R., & Singh, V. K. (2023). Pesticide contamination in agro-ecosystems: Toxicity, impacts, and bio-based management strategies. *Environmental Science and Pollution Research, 30*(4), 9243-9270.

Enhesa. (2024). ISO in numbers: A look behind the ISO 14001 & ISO 45001 boom. Retrieved from https://www.enhesa.com/resources/article/iso-in-numbers-a-look-behind-the-iso-14001-iso-45001-boom/

Epuran, G., Bratucu, G., Bărbulescu, O. U., Neacşu, N. A., & Madar, A. (2018). Food safety and sustainability – an exploratory approach at the level of the Romanian wine production companies. *Amfiteatru Economic, 20*(47), 151-167. doi:10.24818/ea/2018/47/151

European Commission. (2006). *Commission regulation (EC) no 1881/2006 maximum levels for certain contaminants in foodstuffs (text with EEA relevance).* Brussels: European Union

European Commission. (2014). *Commission recommendation of 4 April 2014 on the reduction of the presence of cadmium in foodstuffs (text with EEA relevance).* Brussels: European Union

European Commission (2015). *Commission recommendation (EU) 2015/1381 of 10 August 2015 on the monitoring of arsenic in food.* Brussels: European Union

European Commission. (2019a). *The European Green Deal*. Brussels: European Commission.

European Commission. (2019b). *The European Green Deal (annex)*. Brussels: European Commission

European Commission. (2020a). *EU biodiversity strategy for 2030: Bringing nature back into our lives.* Brussels: European Commission

European Commission. (2020b). *EU biodiversity strategy for 2030: Bringing nature back into our lives (annex)*. Brussels: European Commission.

European Commission. (2020c). *A farm to fork strategy for a fair, healthy and environmentally friendly food system*. Brussels: European Commission. Retrieved from https://www.europarl.europa.eu/committees/en/farm-to-fork-strategy/product-details/20201029CDT04383

European Commission. (2021a). *Commission regulation (EU) 2021/1317 of 9 august 2021 amending regulation (EC) no 1881/2006 as regards maximum levels of lead in certain foodstuffs*. Brussels: European Commission.

European Commission. (2021b). *EU soil strategy for 2030 reaping the benefits of healthy soils for people, food, nature and climate*. Brussels: European Commission.

European Commission. (2022a). *Commission Implementing Decision of 31 August 2022 approving the 2023-2027 CAP strategic plan of Spain (annex I): Overview table*. Brussels: European Commission.

European Commission. (2022b). *Commission Implementing Decision of31 August 2022 approving the 2023-2027 CAP strategic plan of Spain for union support financed by the European agricultural guarantee fund and the European agricultural fund for rural development CCI: 2023ES06AFSP001*. Brussels: European Commission.

European Commission. (2023a). *Annexes to the proposal for a directive of the European parliament and of the council on soil monitoring and resilience (soil monitoring law)*. Brussels: European Commission.

European Commission. (2023b). *Proposal for a Directive of the European parliament and of the council on soil monitoring and resilience (soil monitoring law)*. Brussels: European Commission. doi:10.2777/821504

European Commission (2016). *Commission Notice on the implementation of food safety management systems covering prerequisite programs (PRPs) and procedures based on the HACCP principles, including the facilitation/flexibility of the implementation in certain food businesses* Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52016XC0730(01)&from=ES

European Environment Agency. (2022). *Rethinking-agriculture* . Copenhagen: Denmark: European Environment Agency. doi:10.2800/090009

European Parliament. (2000). *Directive 2000/60/EC of the European parliament and of the council of 23 October 2000 establishing a framework for community action in the field of water policy*. Publications Office of the European Union. doi:10.2785/265789

European Parliament. (2005). *Regulation (EC) no 396/2005 of the European parliament and of the council of 23 February 2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin and amending council directive 91/414/EEC (consolidated text:26/02/2024)*. Brussels: European Union.

European Parliament. (2021a). *European climate law. Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending regulations (EC) no 401/2009 and (EU) 2018/1999*. Brussels: European Union.

European Parliament. (2021b). *Regulation (EU) 2021/2116 of the European parliament and of the council on the financing, management, and monitoring of the common agricultural policy and repealing regulation (EU) no 1306/2013*. Brussels: European Union.

Eurostat. (2023). *Key figures on the European food chain 2023 edition* Publications Office of the European Union. doi:10.2785/265789

Forbes, S. L., De Silva, T., & Gilinsky, A. (2020). Social sustainability in the global wine industry. *Palgrave, Basingstoke, 10*, 978-973.

Gallo, M., Ferrara, L., Calogero, A., Montesano, D., & Naviglio, D. (2020). Relationships between food and diseases: What to know to ensure food safety. *Food Research International, 137*, 109414.

Gehring, K. B., & Kirkpatrick, R. (2020). *Hazard analysis and critical control points (HACCP)*. Cham: Springer International Publishing. doi:10.1007/978-3-030-42660-6_8.

Geoff A. Wilson & Raymond L. Bryant. (1997). *Environmental management*. New York: Roudedge. Taylor & Francis Group.

Ghezzi, S., Ayoun, B., & Lee, Y. M. (2021). Food safety knowledge, training methods, and barriers to training: An examination of the US food truck industry. *Journal of Foodservice Business Research, 24*(5), 534-553.

Gilinsky Jr, A., Newton, S. K., & Vega, R. F. (2016). Sustainability in the global wine industry: Concepts and cases. *Agriculture and Agricultural Science Procedia, 8*, 37-49.

Gołasa, P., Wysokiński, M., Bieńkowska-Gołasa, W., Gradziuk, P., Golonko, M., Gradziuk, B., Gromada, A. (2021). Sources of greenhouse gas emissions in agriculture, with particular emphasis on emissions from energy used. *Energies, 14*(13), 3784.

Hanspach, J., Abson, D. J., French Collier, N., Dorresteijn, I., Schultner, J., & Fischer, J. (2017). From trade-offs to synergies in food security and biodiversity conservation. *Frontiers in Ecology and the Environment, 15*(9), 489-494.

Hermoso, V., Carvalho, S. B., Giakoumi, S., Goldsborough, D., Katsanevakis, S., Leontiou, S., Yates, K. L. (2022). The EU biodiversity strategy for 2030: Opportunities and challenges on the path towards biodiversity recovery. *Environmental Science & Policy, 127*, 263-271.

Hou, D., O'Connor, D., Igalavithana, A. D., Alessi, D. S., Luo, J., Tsang, D. C., . . . Ok, Y. S. (2020). Metal contamination and bioremediation of agricultural soils for food safety and sustainability. *Nature Reviews Earth & Environment, 1*(7), 366-381.

Iannone, R., Miranda, S., Riemma, S., & De Marco, I. (2016). Improving environmental performances in wine production by a life cycle assessment analysis. *Journal of Cleaner Production, 111*, 172-180.

Ingrao, C., Bacenetti, J., Bezama, A., Blok, V., Goglio, P., Koukios, E. G., Zabaniotou, A. (2018). The potential roles of bioeconomy in the transition to equitable, sustainable, post fossil-carbon societies: Findings from this virtual special issue. *Journal of Cleaner Production, 204*, 471-488.

International Organisation of Vine and Wine. (2021). *State of the world vitivinicultural sector in 2020*. France: Organisation Internationale de la Vigne et du Vin. Retrieved from https://www.oiv.int/public/medias/7909/oiv-state-of-the-world-vitivinicultural-sector-in-2020.pdf

International Panel of Experts on Sustainable Food Systems (IPES-Food). (2022). *ANOTHER PERFECT STORM? how the failure to reform food systems has allowed the war in Ukraine to spark a third global food price crisis in 15 years, and what can be done to prevent the next one.*

Jallow, A., Xie, H., Tang, X., Qi, Z., & Li, P. (2021). Worldwide aflatoxin contamination of agricultural products and foods: From occurrence to control. *Comprehensive Reviews in Food Science and Food Safety, 20*(3), 2332-2381.

Knowles, L., & Hill, R. (2001). Environmental initiatives in south African wineries: A comparison between small and large wineries. *Eco-Management and Auditing: The Journal of Corporate Environmental Management, 8*(4), 210-228.

Laca, A., Gancedo, S., Laca, A., & Díaz, M. (2021). Assessment of the environmental impacts associated with vineyards and winemaking. A case study in mountain areas. *Environmental Science and Pollution Research, 28*, 1204-1223.

Lal, R., Delgado, J. A., Groffman, P. M., Millar, N., Dell, C., & Rotz, A. (2011). Management to mitigate and adapt to climate change. *Journal of Soil and Water Conservation, 66*(4), 276-285.

Lal, R. (2016). Soil health and carbon management. *Food and Energy Security, 5*(4), 212-222.

Li, L., Xu, J., Hu, J., & Han, J. (2014). Reducing nitrous oxide emissions to mitigate climate change and protect the ozone layer. *Environmental Science & Technology, 48*(9), 5290-5297.

López-Vicente, M., Calvo-Seas, E., Álvarez, S., & Cerdà, A. (2020). Effectiveness of cover crops to reduce loss of soil organic matter in a rainfed vineyard. *Land, 9*(7), 230.

Marimon, F., Llach, J., & Bernardo, M. (2011). Comparative analysis of diffusion of the ISO 14001 standard by sector of activity. *Journal of Cleaner Production, 19*(15), 1734-1744. doi:10.1016/j.jclepro.2011.06.003

Martin, H., Manzanilla, E. G., More, S. J., O'Neill, L., Bradford, L., Carty, C. I., McAloon, C. G. (2020). Current antimicrobial use in farm animals in the republic of Ireland. *Irish Veterinary Journal, 73*, 1-10.

Martinez-Rodriguez, A. J., & Carrascosa, A. V. (2009). HACCP to control microbial safety hazards during winemaking: Ochratoxin A. *Food Control, 20*(5), 469-475. doi:10.1016/j.foodcont.2008.07.015

Martucci, O., Arcese, G., Montauti, C., & Acampora, A. (2019). Social aspects in the wine sector: Comparison between social life cycle assessment and VIVA sustainable wine project indicators. *Resources, 8*(2), 69.

McGreevy, S. R., Rupprecht, C. D. D., Niles, D., Wiek, A., Carolan, M., Kallis, G., . . . Tachikawa, M. (2022). Sustainable agrifood systems for a post-growth world. *Nature Sustainability,* Retrieved from https://www.narcis.nl/publication/RecordID/oai:ris.utwente.nl:publications%2F342bd8d2-2afb-4b57-9215-4084072b71fa

Mielcarek-Bocheńska, P., & Rzeźnik, W. (2021). Greenhouse gas emissions from agriculture in EU countries—state and perspectives. *Atmosphere, 12*(11), 1396.

More, S. J. (2020). European perspectives on efforts to reduce antimicrobial usage in food animal production. *Irish Veterinary Journal, 73*(1), 2.

Mortimore, S., & Wallace, C. (2013). *HACCP: A practical approach* Springer Science & Business Media.

Mthombeni, D. L., Antwi, M. A., & Oduniyi, O. S. (2022). Factors influencing access to agro-processing training for small-scale crop farmers in Gauteng province of south Africa. *Agriculture & Food Security, 11*(1), 31.

Munishi, L. K., Ndakidemi, P. A., Blake, W., Comber, S., & Hutchinson, T. H. (2021). Toxic metals in east African agro-ecosystems: Key risks for sustainable food production. *Journal of Environmental Management, 294*, 112973.

Myers, S. S., Smith, M. R., Guth, S., Golden, C. D., Vaitla, B., Mueller, N. D., Huybers, P. (2017). Climate change and global food systems: Potential impacts on food security and undernutrition. *Annual Review of Public Health, 38*, 259-277.

Neves, F. d. O., Salgado, E. G., & Beijo, L. A. (2017). Analysis of the environmental management system based on ISO 14001 on the American continent. *Journal of Environmental Management, 199*, 251-262. doi:10.1016/j.jenvman.2017.05.049

Novara, A., Cerda, A., Barone, E., & Gristina, L. (2021). Cover crop management and water conservation in vineyard and olive orchards. *Soil and Tillage Research, 208*, 104896.

O'Mara, F. P. (2011). The significance of livestock as a contributor to global greenhouse gas emissions today and in the near future. *Animal Feed Science and Technology, 166*, 7-15.

Oenema, O., Ju, X., de Klein, C., Alfaro, M., del Prado, A., Lesschen, J. P., Gao, B. (2014). Reducing nitrous oxide emissions from the global food system. *Current Opinion in Environmental Sustainability, 9*, 55-64.

Organisation Internationale de la Vigne et du Vin. (2022). *INTERNATIONAL OENOLOGICAL CODEX general principles*. France: Organisation Internationale de la Vigne et du Vin.

Osborne, J. P. (2022). Advances in microbiological quality control. *Managing wine quality* (pp. 207-241) Elsevier.

Paull, J. (2024). Organic agriculture in Europe: EU sets goal of growing organic farmland from 10% to 25% by 2030. *European Journal of Agriculture and Food Sciences, 6*(1), 26-31.

Pe'er, G., Bonn, A., Bruelheide, H., Dieker, P., Eisenhauer, N., Feindt, P. H., Lomba, Â. (2020). Action needed for the EU common agricultural policy to address sustainability challenges. *People and Nature, 2*(2), 305-316.

Pomarici, E. (2016). Recent trends in the international wine market and arising research questions. *Wine Economics and Policy, 5*(1), 1-3.

Pomarici, E., Corsi, A., Mazzarino, S., & Sardone, R. (2021). The Italian wine sector: Evolution, structure, competitiveness and future challenges of an enduring leader. *Italian Economic Journal, 7*(2), 259-295.

Prandecki, K., Wrzaszcz, W., & Zieliński, M. (2021). Environmental and climate challenges to agriculture in Poland in the context of objectives adopted in the European green deal strategy. *Sustainability, 13*(18), 10318.

Rajkovic, A., Jovanovic, J., Monteiro, S., Decleer, M., Andjelkovic, M., Foubert, A., Madder, A. (2020). Detection of toxins involved in foodborne diseases caused by gram-positive bacteria. *Comprehensive Reviews in Food Science and Food Safety, 19*(4), 1605-1657.

Sarker, A., Kim, J., Islam, Abu Reza Md Towfiqul, Bilal, M., Rakib, M. R. J., Nandi, R., Islam, T. (2022). Heavy metals contamination and associated health risks in food webs—a review focuses on food safety and environmental sustainability in Bangladesh. *Environmental Science and Pollution Research, 29*(3), 3230-3245.

Simionescu, M., Bilan, Y., Gędek, S., & Streimikiene, D. (2019). The effects of greenhouse gas emissions on cereal production in the European union. *Sustainability, 11*(12), 3433.

Smith, P., Ashmore, M. R., Black, H. I., Burgess, P. J., Evans, C. D., Quine, T. A., Orr, H. G. (2013). The role of ecosystems and their management in regulating climate, and soil, water and air quality. *Journal of Applied Ecology, 50*(4), 812-829.

Srivastav, A. L. (2020). Chemical fertilizers and pesticides: Role in groundwater contamination. *Agrochemicals detection, treatment, and remediation* (pp. 143-159) Elsevier.

Summers Raines, S. (2002). Implementing ISO 14001—An international survey assessing the benefits of certification. *Corporate Environmental Strategy, 9*(4), 418-426. doi: https://doi.org/10.1016/S1066-7938(02)00009-X

Tenzer, H., Pudelko, M., & Zellmer-Bruhn, M. (2021). The impact of language barriers on knowledge processing in multinational teams. *Journal of World Business, 56*(2), 101184.

Todd, E. (2020). Food-borne disease prevention and risk assessment. *International Journal of Environmental Research and Public Health, 17*(14), 5129.

Uzman, D., Reineke, A., Entling, M. H., & Leyer, I. (2020). Habitat area and connectivity support cavity-nesting bees in vineyards more than organic management. *Biological Conservation, 242*, 108419.

Vågsholm, I., Arzoomand, N. S., & Boqvist, S. (2020). Food security, safety, and sustainability—getting the trade-offs right. *Frontiers in Sustainable Food Systems,* , 16.

Vermeulen, S. J., Campbell, B. M., & Ingram, J. S. (2012). Climate change and food systems. *Annual Review of Environment and Resources, 37*, 195-222.

Wagner, M., Stanbury, P., Dietrich, T., Döring, J., Ewert, J., Foerster, C., Koch, M. (2023). Developing a sustainability vision for the global wine industry. *Sustainability, 15*(13), 10487.

Yapp, C., & Fairman, R. (2006). Factors affecting food safety compliance within small and medium-sized enterprises: Implications for regulatory and enforcement strategies. *Food Control, 17*(1), 42-51. doi:10.1016/j.foodcont.2004.08.007

Zhang, L., Ye, F., Yang, L., & Zhou, G. (2019). Impact of political connections on corporate environmental performance: From a green development perspective. *Sustainability, 11*(5), 1317.

Annexes

Annex A. Comprehensive Summary of Prior Research

- **Food Safety and Sustainability–An Exploratory Approach at the Level of the Romanian Wine production Companies**. Epuran, G., Brătucu, G., Bărbulescu, O., Neacșu, N. A., & Madar, A. (2018). Amfiteatru Economic, 20 (47), 151-167. (Epuran, Bratucu, Bărbulescu, Neacșu, & Madar, 2018)

This article explores the implementation of sustainable development practices and strategies in the wine industry and its relationship to FS. The study conducted qualitative marketing research by interviewing fifteen managers from Romanian wine-producing companies. The research aims to understand the willingness of these companies to adopt marketing strategies that contribute to increasing food security and wine quality based on sustainability principles. The article highlights the association between responsible wine consumption, FS, and sustainability, emphasizing their importance in the European Union and beyond.

The research findings indicate that while the principles of sustainability in the wine sector are recognized, only one company partially addresses them from a strategic perspective. Bio certifications are considered by nine out of fifteen managers, but the advantages obtained are perceived as minor compared to the excessive costs and limitations associated with them. The costs for bio-wine production are attributed to field practices rather than ensuring quality and FS. Additionally, consumers do not associate eco-labelling with sustainability, perceiving it more as a marketing action.

Regarding the use of modern technologies, the interviewed managers acknowledge the emphasis placed on increasing FS and wine quality using Machine to Machine (M2M) and Internet of Things (IoT) technologies. However, the European legislation in this regard is considered burdensome and costly, leading to decreased competitiveness, especially for smaller producers. Large companies have implemented monitoring stations for climatic parameters and utilize M2M and IoT technologies, while smaller companies have limited use of these technologies.

In terms of marketing strategies, various techniques are employed, including sommelier promotion, online presence, tastings, participation in fairs, and collaborations with associations and producers. The article also mentions winery tours, virtual tours, and modern marketing techniques such as websites, blogging, and online stores. Different strategies are used to strengthen the perception of FS, such as personalized labelled wines for corporate events, the establishment of clubs, and associations with reputable organizations like the Royal House of Romania.

The study highlights the correlation between wine consumption, FS, and elements of education, culture, and civilization. The managers emphasize that wine should be consumed in limited quantities and promote its consumption in a cultural and educational context. They relate wine consumption to events, institutions, and traditions associated with wine, emphasizing the importance of continuous education in this field. The article concludes that FS, sustainability, and strategic approaches vary in importance among wine-producing companies in Romania. While some steps have been taken, the strict observance of environmental regulations presents economic, financial, and social obstacles to achieving long-term environmentally friendly or bio-friendly wine production.

Summarizing, the article examines the willingness of wine industry managers to adopt marketing strategies that enhance food security and wine quality within the context of sustainable development. It discusses the challenges and benefits associated with sustainability practices, the use of modern technologies, marketing techniques, and the connection between wine consumption, FS, education, culture, and civilization. The research contributes to a comprehensive understanding of the complex relationship between FS and sustainability in the wine industry.

- **Sustainability in the global wine industry: Concepts and cases.** Gilinsky Jr, A., Newton, S. K., & Vega, R. F. (2016). Agriculture and agricultural science Procedia, 8, 37-49. (Gilinsky Jr, Newton, & Vega, 2016)

This paper explores the relationship between sustainability and the wine industry, emphasizing the importance of leaving the land in better shape for future generations. The global wine industry, consisting mostly of small-medium enterprises, faces environmental challenges such as rising energy prices, water scarcity, chemical exposure concerns, and climate change. The adoption of sustainable practices can mitigate these threats and lead to product innovation, pollution prevention, and stewardship of natural resources. The incorporation of EMS is one aspect of the broader sustainability strategy adopted by wine businesses.

it highlights that sustainable processes and products can provide a competitive advantage and improve business performance. However, incumbent businesses may resist adopting sustainable systems due to concerns about cannibalizing existing product lines. On the other hand, younger and entrepreneurial agricultural businesses show a propensity for investing in sustainable innovations. The goal of a sustainable wine business is to achieve a "sweet spot" where environmental and social impacts are minimized while maintaining financial viability.

Besides, it outlines three elements of a triple-bottom-line strategy for sustainable wine businesses: social stewardship, environmental stewardship, and financial stewardship. Social stewardship involves fostering a shift in the company's social attitude towards the environment and its inhabitants. Environmental stewardship entails implementing practices and policies with positive environmental impacts, including EMS, energy conservation, and reduced carbon footprint. Financial stewardship aligns these concepts with an overarching framework that capitalizes on the positive benefits, such as better margins and reduced operating costs.

Research also emphasizes the learning objectives, including broadening the understanding of sustainability in the wine industry, developing metrics for benchmarking wine business sustainability, analysing, and comparing wine businesses using sustainability benchmarks, and providing practical experience in evaluating sustainable strategies through case studies.

The four case studies presented in the paper illustrate different regional approaches and decisions made by wineries to ensure their sustainability. These case studies offer longitudinal evidence and highlight the diverse strategies employed by wine businesses in becoming sustainable. While limitations in case availability prevent a comprehensive representation, the studies shed light on the practices and challenges faced by wineries in their sustainability journey.

In conclusion, Gilinsky Jr's (2016) research provides compelling evidence for the emergence of sustainable wine businesses on a global scale. The study emphasizes the significance of EMS as a valuable tool for implementing environmental sustainability practices within the wine industry.

- **What is sustainability in the wine world? A cross-country analysis of wine sustainability frameworks.** Flores, S.S. (2018). Journal of cleaner production, 172, 2301-2312. (Flores, 2018)

This research emphasizes the significance of sustainability in the wine industry and highlights the role of EMS, such as ISO 14001, in promoting sustainable practices. It acknowledges the increasing demand for sustainability from customers and markets and the need for continued progress in addressing sustainability challenges. The article recognizes the threats posed by sustainability issues like climate change, chemical exposure, and water and energy availability, while also acknowledging the competitive advantage and market strategy that sustainability can provide.

Empirical studies show that customers value sustainable winemaking practices and are willing to pay higher prices for sustainable products. Producers also benefit from adopting sustainable practices, particularly in terms of environmental improvement and economic efficiency. While economic results may be more favourable for stakeholders, internal motivation is a significant driver for producers to adopt sustainability practices.

It highlights the official documents and frameworks provided by the OIV as a foundation for defining sustainable viticulture. These frameworks encompass environmental, social, economic, and cultural aspects of sustainability in the wine industry. Wine regions have also developed their own frameworks to adapt sustainability practices to local contexts and address specific issues. Sustainability assessment and frameworks play a crucial role in translating sustainability principles into practice.

The article categorizes sustainability frameworks into six types, including self-assessment, footprint, protocol, guide, and certification or label. These frameworks provide a comprehensive view of sustainability issues and support decision-making, management processes, and continuous improvement in sustainability performance.

Besides, it describes a study that analyses sustainability frameworks in the wine industry. The study employs a qualitative method and collects data from literature reviews, document searches, and expert consultations. It is divided into two phases: an exploratory study to select reference countries and frameworks, and a content analysis of the sustainability frameworks. The selected frameworks represent a diverse range of geographical distribution and production profiles, including both "New World" and "Old World" wine producers. The analysis focuses on identifying common trends, guidelines, and indicators used to measure sustainability, as well as evaluating the structure, governance, and learning potential of the frameworks.

In conclusion, it underscores the need for sustainability in the wine industry and highlights the role of EMS and frameworks in promoting sustainable practices. It discusses customer perception, advantages for producers, official definitions and frameworks, and the variety of sustainability assessment tools available. The article also presents the findings of a study that analyses sustainability frameworks, providing insights into their characteristics and potential for improvement. It emphasizes the importance of context-specific sustainability initiatives and the need for further research to enhance understanding and effectiveness in the wine industry.

- **Qualitative evaluation of three ‘environmental management systems’ in the New Zealand wine industry**. Hughey, K. F., Tait, S. V., & O'Connell, M. J. (2005).

Journal of Cleaner Production, 13(12), 1175-1187. (Hughey, Tait, & O'Connell, 2005)

This research presents a comparative evaluation of three EMS used in the New Zealand wine industry: Sustainable Winegrowing New Zealand (SWNZ), ISO 14001, and Bio-Gro. The study aims to assess the strengths and performance of these systems in terms of sustainability considerations, implementation, marketing, and their relationship with broader aspects of EM in New Zealand.

The evaluation reveals that each EMS system has its own strengths, and there is no clear superiority of one system over the others. However, the implementation of an industry-specific system like SWNZ, in combination with a generic process-based system like ISO 14001, contributes to the development of a more sustainable wine industry. The study emphasizes the importance of considering economic, environmental, and social factors, as well as the specific characteristics of the New Zealand wine industry, when evaluating EMS performance.

The article highlights the need for companies and the industry to identify unsustainable practices and set short-term goals toward long-term sustainability. It also addresses challenges and criticisms related to the implementation and effectiveness of these EMS systems, such as the lack of eco-labelling for SWNZ-accredited companies and the confidentiality of environmental information in ISO 14001.

it discusses the results of a survey on the environmental and social effectiveness, business implications, system issues, and environmental sustainability of different certification systems used in the New Zealand wine industry. The survey found that SWNZ, ISO 14001, and Bio-Gro companies had varying levels of improvement in areas such as spray usage, soil and sward management, waste reduction, accountability, staff safety, and chemical leaching.

The reasons for choosing each system varied, with SWNZ chosen for its progressive and appropriate nature, industry support/recognition, flexibility, and sustainability outcomes; ISO 14001 chosen for its flexibility, choice in targets, accountability, and processes; and Bio-Gro chosen for compatibility with company philosophy, ambitious standards, organic branding, and sustainability.

This article emphasizes the importance of sustainable management in the context of New Zealand's environmental legislation and suggests that integrating EMS systems with Triple Bottom Line reporting could strengthen the promotion of sustainability in the wine industry. The article also discusses the potential policy implications, such as introducing legislation to require EMS adoption and further promoting sustainability through industry-wide strategies.

In conclusion, the study highlights the advantages and disadvantages of different EMS systems used in the New Zealand wine industry and emphasizes the need for a broader industry-wide strategy to promote sustainability. The findings provide valuable insights for policymakers and businesses seeking to implement EMS in the wine industry and maintain the industry's clean and green image.

- **An Exploratory Study of the Sustainable Practices Used at Each Level of the Bordeaux Wine Value Chain.** Tahon, C., & Batt, P. J. (2021). Sustainability, 13(17), 9760. (Tahon & Batt, 2021)

The article examines the environmental and socially sustainable practices in the Bordeaux wine value chain (WVC) and explores the alignment of different actors in terms of their beliefs and implementation of sustainable practices. The study finds that environmentally sustainable practices are more developed and widely adopted by most actors in the WVC compared to socially sustainable practices. Wine grape growers focus on soil management, reducing the use of phytosanitary products, water management, biodiversity preservation, and minimizing CO_2 emissions. They employ techniques such as adding organic matter to the soil, using on-farm meteorological stations, and implementing integrated pest control methods. Wineries focus on reducing energy consumption through LED lighting systems, solar panels, and improving the cooling of wine tanks. Water management, packaging sustainability, and shorter distribution chains are also identified as important sustainability practices.

The use of EMS is implied in the article, as it discusses various practices employed by different actors in the Bordeaux wine value chain to promote sustainability. These practices align with the core principles of EMS, which involve identifying and managing environmental aspects, complying with regulations, and continuously improving environmental performance. Wine grape growers and wineries implement practices such as reducing the use of phytosanitary products, minimizing CO_2 emissions, and employing sustainable water management techniques. These actions demonstrate an initiative-taking approach towards environmental sustainability and indicate the potential use of EMS in guiding and formalizing these practices.

This research also highlights the importance of shorter distribution chains to reduce CO_2 emissions and improve control over pricing, which aligns with the concept of sustainable supply chain management. Distributors express an interest in nonconventional agricultural practices and prefer wines that adhere to biodynamic or organic agriculture principles. This emphasis on sustainable production methods suggests a potential application of EMS in ensuring the selection and sourcing of sustainable suppliers within the value chain. Overall, the article underscores the relevance of EMS and sustainability practices in the Bordeaux wine industry, emphasizing the need for ongoing efforts to achieve both environmental and social sustainability throughout the value chain.

- **Food Security, Safety, and Sustainability—Getting the Trade-Offs Right**. Vågsholm, I., Arzoomand, N. S., & Boqvist, S. (2020). Food security, safety, and sustainability—getting the trade-offs right. Frontiers in Sustainable Food Systems, 16. (Vågsholm, Arzoomand, & Boqvist, 2020)

This research text highlights the interconnectedness of FS, food security, and sustainability in achieving a sustainable future. It emphasizes the need to align the goals of FS and security to achieve United Nations sustainable development goals. Various approaches, such as reducing food waste and shifting towards plant-based diets, are discussed as potential solutions. The complexity of food chains and the importance of a One Health approach to assess trade-offs and address public health, sustainability, and FS issues are stressed. The introduction also mentions the emerging concern of food fraud. The paper aims to explore and discuss trade-offs among these aspects, following the food recovery hierarchy outlined by the US Environmental Protection Agency.

Sustainable food security is a multifaceted challenge. It involves ensuring food availability, access, nutrition, safety, and stability. Threats to food security include limited access to safe and nutritious food, rising food prices, and social unrest. As the global population grows, addressing this challenge requires changes in food supply chains and reducing food waste. Additionally, diverting edible crops to biofuel production and food price speculation are concerns. Urbanization complicates food security, as urban populations rely on purchasing food and are vulnerable to price fluctuations.

FS and environmental sustainability are critical considerations. Ensuring FS is important, but it should not lead to unnecessary food wastage. Balancing environmental sustainability with social and economic goals is essential. Managing trade-offs between these objectives is key to addressing sustainable food security effectively.

Also, food losses and waste have significant implications for both food security and sustainability. Approximately one-third of the food produced globally is lost or wasted, resulting in substantial economic, environmental, and social costs. These losses not only represent a major business opportunity but also contribute to resource inefficiencies and greenhouse gas emissions. Addressing food loss and waste is crucial for ensuring food security, reducing environmental impacts, and achieving sustainability goals. Strategies such as using advanced technologies (e.g., AI and sensors), improving labelling, and adopting blockchain technology can help reduce food waste, enhance FS, and streamline the food supply chain. Additionally, a shift in perspective is suggested, treating food security as an "insurance question" to minimize food waste and ensure a sustainable future.

Intensification of food production must be in line with long-term sustainability goals. Sustainable agriculture and aquaculture should operate within environmental boundaries and consider ecological dimensions, resource footprints, social dimensions, and food security. To address the challenges of a growing global population and shrinking arable land, various strategies are proposed, including reducing food losses during production, shifting to novel animal proteins, and focusing on animal nutrition and disease prevention. Additionally, the text emphasizes the unsustainable use of antimicrobials in food production, which contributes to antimicrobial resistance (AMR) and poses risks to public health. To ensure sustainability, efforts should be directed toward improved animal welfare, biosecurity, preventive medicine, and the prudent use of antimicrobials in both human and veterinary medicine.

Circular food production systems have several facets, with a primary emphasis on FS. It encompasses the processes of redistributing, reprocessing, and recycling food, emphasizing key aspects:

In the realm of food redistribution, efforts are made through food banks and donation programs to assist disadvantaged groups, yet concerns arise as donated food approaches its expiration date, raising questions about safety. Liability issues, notably those linked to foodborne illnesses, can deter potential donors. Some countries have introduced protective legislation to encourage contributions. Effective food donation programs have the potential to mitigate hunger among vulnerable communities, but they often grapple with resource limitations for transportation and storage. The integration of artificial intelligence, such as neural networks, can enhance the prediction of food supplies. It is imperative that FS remains a cornerstone for the success of food donation initiatives.

Reprocessing food items nearing their "best before" or "use by" dates is a strategy to reduce waste and bolster sustainability. Repurposing food waste into animal feed can optimize resource usage but necessitates careful treatment to eliminate potential pathogens. An innovative approach involves using insects to recycle food waste, although this raise concerns related to bacteria, heavy metals, and allergic reactions, necessitating further research to manage safety risks effectively. Circular food production systems hold promise, reducing waste and environmental impact. However, they also introduce new risks, particularly concerning diseases in animal feed. The “mad cow disease” (BSE) outbreak in the United Kingdom serves as a sobering example, highlighting the importance of managing biological and chemical hazards, maintaining public trust, and addressing delays in implementing control measures.

Circular food production systems offer significant benefits but require meticulous management of FS and public trust. Valuable insights from past outbreaks like BSE can offer invaluable guidance in their development and implementation.

Strategies for recovering energy and nutrients from food losses, waste, and byproducts, with a focus on their implications for sustainability, food security, and FS.

One strategy involves recovering biogas and nutrients from animal manure, presenting a potential win-win situation for sustainability and food security. However, it comes with FS risks, especially when dealing with concentrated manure from poultry and pig farms, which could harbour pathogens like the avian flu virus. Different methods like composting, anaerobic digestion, and ammonia treatment are available for nutrient and energy recovery, each with its own advantages and disadvantages. Controlling pathogens in fertilizer production primarily depends on time-temperature profiles and ammonia content.

Biofuel production, including biogas, bioethanol, biodiesel, and biobuthanol, offers another avenue for energy recovery. To ensure sustainability, substrates for biofuels should not compete with human food or animal feed. However, the link between oil and food prices raises concerns about food security and social sustainability when edible foods are diverted into biofuel production.

While incineration and landfills are considered fewer desirable strategies, incineration can be a sustainability option in developing countries with energy poverty, using food waste as a local energy resource. In contrast, landfills have large environmental footprints and pose biosecurity and FS risks due to vermin presence.

These strategies for recovering energy and nutrients from food-related waste involve trade-offs between FS, sustainability, and food security, highlighting the need for careful consideration and case-specific approaches.

In conclusions, feeding ten billion people in 2050 sustainably will require changes of our food chains. Changing of our food demand to more plant-based diets could help as half of the world's cereal production ends up as animal feed while only around one third is for human nutrition. The future diets might align with recommendations of the EAT-Lancet report, but with local adaptions. For example, the beef, mutton, and milk produced from pastoral farming systems will remain. The ecosystem benefits of open landscapes should give further incentives for pastoral farming practices. Moreover, seafood produced through farming and in circular systems could supply high quality proteins wherever this production is feasible. Another major source of food supply could emerge if the 30% of food produced that is now lost or wasted, could become available for human consumption. Source reduction and reprocessing of foods are the best options to eliminate food waste or loss. One example of sustainable intensification and source reduction could be intensifying the harvest of vegetable crops to double the output with the same footprint. This will require consumers and food businesses to adapt their quality requirements and specifications. If the global food systems could change in this direction, the global food security will improve and be more resilient. Using modern IT technology offers the best promise of more efficient source reduction, reprocessing, and recycling of food.

It is, however, vital to get the trade-offs right between FS, food security and economic, social, and environmental sustainability. These trade-offs should be evidence and risk based. Good intentions will not compensate for failures as shown by the failed use of antimicrobials to achieve food security through intensifying food production. A veterinary medicine and food value chain not requiring antimicrobials is therefore a necessary aim for research and innovation. The transition of animal production from intensive cereal-based farming to more extensive pastoral farming will imply changes to veterinary medicine. For example, nutritional supplements and control of parasites may become bigger concerns than diseases related to rapid growth. In conclusion, the trade-offs and subsequent decisions regarding FS, food security, and sustainability are not trivial and should be evidence based.

Annex B. Survey Case Study One

Survey for the Analysis of Implementation and Deployment of HACCP System in Wineries Producing Red Wine. *Indicates that the question is mandatory.

Email Address*

G.0 What is your annual production level of young red wine? Mark only one oval.

- o up to 25,000 litres/year
- o between 25,001 and 100,000 Liters/year
- o between 100,001 and 250,000 litres/year
- o between 250,001 and 500,000 Liters/year
- o more than 500,001 litres/year

G.1 Do you have implemented a prerequisite program according to the food hygiene legislation? *. Mark only one oval.

o Yes / o No

G.2 Indicate which type of prerequisite plans you have implemented*. Select all that apply.

☐ G.2.1 Maintenance of premises, facilities, and equipment
☐ G.2.2 Good Manufacturing Practices Plan
☐ G.2.3 Cleaning and disinfection plan
☐ G.2.4 Waste control plan
☐ G.2.5 Pest control plan
☐ G.2.6 Control plan for water supply
☐ G.2.7 Traceability control plan
☐ G.2.8 Supplier control plan
☐ G.2.9 Allergen control plan
☐ G.2.10 Worker training plan

G.3 Do winery operators have training related to good viticulture practices (BPV)?*. Mark only one oval.

- o No operator has BPV training.
- o More than half of the operators have BPV training.
- o All operators have BPV training.

G.4 Do winery operators know the prerequisite plans implemented in the winery? *. Mark only one oval.

- o No operator is aware of the implemented prerequisite plans.
- o More than half of the operators are aware of the implemented prerequisite plans.
- o All operators are aware of the implemented prerequisite plans.

G.5 Does the winery have a specific annual budget for the execution of the prerequisite plans? *. Mark only one oval.

- The winery does not have any annual budget for this matter.
- The winery carries out plans as needed but does not have a detailed annual budget.
- The winery has a detailed annual budget, which it executes in a planned manner.

G.6 Does the winery have implemented a Hazard Analysis and Critical Control Points (HACCP) System? *. Mark only one oval.

o Yes / o No

Harvest and Transportation

2.1 Are periodic inspections carried out in the vineyards prior to the harvest? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

2.2 Are inspections conducted in the vineyards during the harvest to control hygiene measures during this stage? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

2.3 Is the time taken to transport grapes destined to produce red wine measured from the vineyard to the winery? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

Receipt of the harvest at the winery

3.1 Is the measurement of residues of fungicides and/or pesticides in grapes destined to produce red wine carried out when received at the winery? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

3.2 Is the presence of mycotoxins from rotting grapes checked? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

3.3 Is the presence of contamination by metals (Cadmium, Lead, Arsenic) in grapes checked? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

3.4 Is the presence of contamination by vegetable residues, dust, and/or metallic elements in grapes checked? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

Pre-fermentation Treatments

4.1 Is the cleanliness of tanks controlled to eliminate residues of microorganisms? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

4.2 Is the absence of cleaning and disinfection products from performing these tasks in the tanks controlled? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

Grape Crushing and Paste Pumping

5.1 Is it controlled that the maintenance time of the must in the crusher is less than two hours? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

5.2 Is the cleanliness of the crushing equipment controlled with a frequency not exceeding two days? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

5.3 Is the absence of cleaning and disinfection products from performing these tasks in the tanks, press, and/or pumping equipment controlled? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

Sulfiting and Fermentation

6.1 Is the safety and purity of additives controlled? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

6.2 Is the absence of microorganisms in the equipment and tanks controlled? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

Alcoholic Fermentation, Maceration, Racking, Pressing of Grape Pomace, Malolactic Fermentation, and Finishing Fermentation

7.1 Is the concentration of ethyl carbamate in the fermented must controlled? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

7.2 Is the concentration of Sulphur dioxide in the fermented must controlled? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

7.3 Is the purity and safety of yeasts controlled? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

7.4 Is the temperature controlled during fermentation? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

7.5 Is the pH of red wine controlled during malolactic fermentation? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

7.6 Is hygiene controlled during racking and pressing operations? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

7.7 Is the cleanliness of pressing equipment controlled with a frequency not exceeding two days? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

Racking, Clarification, and Filtration

8.1 Are the cleaning procedures for tanks and racking equipment controlled? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

8.2 Are the maintenance and cleaning procedures of the facilities controlled during the racking stage? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

8.3 Is the purity and safety of the agents used as clarifiers in red wine controlled? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

8.4 Is the absence of residues from the agents used as clarifiers in red wine controlled? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

8.5 Is the absence of foreign elements from the filters in red wine controlled? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

8.6 Are hygiene operations controlled during clarification and filtration operations? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

8.7 Is the absence of cleaning and disinfection products from racking, clarification, and filtration tasks in tanks and/or equipment controlled? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

Cold Stabilization

9.1 Are the limit concentrations of metals (traces of As, Cu, Pb) in red wine controlled? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

9.2 Is it controlled that the additives used are those allowed by current food legislation? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

Bottling and Labelling

10.1 Are bottle cleaning procedures controlled? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

10.2 Are maintenance and cleaning procedures for the red wine bottling line controlled? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

10.3 Is there microbiological control of the red wine bottling line and bottles? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

10.4 Is it controlled that the cork or similar plug used for closing the bottles has undergone microbiological control? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

10.5 Is it controlled that the label used is correctly coded? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

10.6 Is it controlled that the label used correctly describes mandatory information about allergens? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

10.7 Is it controlled that the label used correctly describes information about the Denomination of Origin Vinos de Madrid? *. Mark only one oval.

Never (0) / Hardly ever (1) / Usually (2) / Always (3).

Application of HACCP Principles

11.1 Have the winery's managers set objective and critical limit levels for each of the identified critical points? *. Mark only one oval.

- No, for none of them.
- Yes, but only for those where applicable mandatory regulations exist.
- Yes, for each and every one of them following applicable mandatory regulations and/or professional technical recommendations.

11.2 Has the winery established a monitoring system for critical control points? *. Mark only one oval.

o Yes / o No

11.3 If a CCP monitoring system is established, what checking methods are used? *. (Check all that apply from the following list). Select all that apply.

- Visual observation
- Sensory evaluation (smell, taste, aroma, texture)
- Physical determinations (Temperature, Relative humidity, pH)
- Chemical analysis
- Microbiological analysis

11.4 Does the winery have a written monitoring program detailing the surveillance activities of hazards and their CCPs at each stage of red wine production? *. Mark only one oval.

o Yes / o No

11.5 Does the winery have a written procedure for establishing corrective measures to be applied in case of deviations in each critical control point (CCP? *. Mark only one oval.

o Yes / o No

11.6 Does the winery have a procedure for verifying the effectiveness of the CCP control system? *. Mark only one oval.

o Yes / o No

11.7 If yes, does this verification procedure detail the frequency of control for each critical control point (CCP) and the responsible person in charge of performing it? *. Mark only one oval.

o Yes / o No

11.8 If yes, please indicate which people participate in verifying the effectiveness of the CCP system. Check all options that apply.

- Winery owner
- Winery manager
- Quality manager or similar
- Winemaker
- Operators
- Others

11.9 Does the winery conduct an annual internal audit of the Critical Control Points and Control Analysis (CCP)? *. Mark only one oval.

- No
- Yes, but with a frequency greater than one year.
- Yes, annually.

11.10 Does the winery have a record and documentation system for the HACCP system? *. Mark only one oval.

- There are no records or written documents.
- Yes, there are records and written documents, but they are not complete or not updated periodically.
- Yes, there is a complete and periodically updated record and documentation system.

11.11 If yes, what documents does the winery's HACCP system contain? (Check all options that apply.)

- List of HACCP system team members
- Description of stages and production process of red wine
- Analysis of hazards and determination of preventive measures
- Identification of Critical Control Points (CCP)
- Surveillance program containing surveillance activities
- Corrective measures procedure
- Results of verifications and internal audits
- Document and record management procedure
- Records generated by the HACCP system.

Annex C. Survey Case Study Two

Analysis of wineries performance about Critical Control Point related to risk control contamination by arsenic, cadmium, and lead in grapes/wines during winemaking.
* Obligatory

General data of the winery

G.1 What is your annual level of red wine production? * (Mark only one)
up to 25,000 litres/year
between 25,001 and 100,000 litres/year
between 100,001 and 250,000 litres/year
between 250,001 and 500,000 litres/year more than 500,001 litres/year

G.2 Do you have a prerequisite program in place, according to the legislation on food hygiene? * (Mark only one)
Yes / No

G.3 Does the winery have a Critical Point Analysis System in place and Control (HACCP)? * (Mark only one)
Yes / No

G.4 How many people work in wine production operations in the winery? *

G.5 Do winery workers have training about good manufacturing practices (GMP)? * (Mark only one)
No worker has GMP training.
More than half of workers have GMP training.
All workers have GMP training.

G.6 Do winery workers have control training and monitoring of critical points (CCPs)? * (Mark only one)
No worker has training in control and monitoring of CCPs.
More than half of workers have training in control and monitoring of the CCPs.
All workers have training in control and monitoring of the CCPs.

Information available on arsenic, cadmium and leads in the raw material (Critical Control Point)

ID 1. The winery has identified the legislation relating to food contamination by: (check all those you consider).
Arsenic / Cadmium / Lead
ID 2. The winery uses the updated information available from the Spanish Agency for Food Safety and Nutrition (AESAN) on heavy metals food risk. * (Mark only one)
Yes / No

CS 1. Does the winery have information related to physic-chemical analysis of where do the grapes used in winemaking come from? * (Mark only one)
Yes (Skip to question 11) / No

CS 2. Does the winery have information on the fertilizers used in the fertilization of the soil from which the grapes used in winemaking come from? * (Mark only one)
Yes / No

Information available of the concentration of arsenic, cadmium, and lead in the soil

CS 3. The available information on the analysis of vineyard arable soil holds data on:
Select all that apply.

Total Arsenic Concentration in Soil
Concentration of Arsenic Available in Soil
Total Cadmium Concentration in Soil
Cadmium Concentration Available in Soil
Total Lead Concentration in Soil
Lead Concentration Available in Soil
Soil pH
Electrical conductivity of the soil

Control of the raw material (analysis procedures in the winery)

CB 1. Does the winery have its own laboratory to perform chemical analysis of grapes and wines? * (Mark only one)
Yes / No

CB 2. If you do NOT have your own laboratory, do you use an external laboratory to perform chemical analysis of grapes and wines? * (Mark only one)
Yes / No

CB 3. Does the warehouse have the technology and personnel to perform metal analysis using atomic absorption spectrometry? * (Mark only one)
Yes / No

CB 4. If you do NOT have your own laboratory, do you use an external laboratory to perform metal analysis using atomic absorption spectrometry on grapes and wines? *
Yes / No

Professional profile that performs the survey

You can tell us about your job inside the winery. (Mark only one)
Owner
Director/Manager
Winemaker
Winery Operator
Administrative/management/commercial staff
Other

Annex D. Survey Case Study Three

Environmental management system questionnaire (Italy)
* Obligatory

1. Company name*
2. E-mail address *
3. S1.1 Annual production capacity. Mark only one oval.

- Less than 50,001 litres/year.
- 50,001 litres/year - 100,000 litres/year.
- 100,001 litres/year - 250,000 litres/year.
- 250,001 litres/year - 1,000,000 litres/year.
- More than 1,000,000 litres/year.

4. S1.2 Number of employees. Mark only one oval.

- < 10.
- 10 to 49.
- 50 to 249.
- 250.

5. S1.3 Job position in the company. Mark only one oval.

- General Manager.
- Owner Manager.
- Ecological Manager.
- Administration Officer.
- Vineyard Manager Executive Director.
- Other

6. S2.1 What are the company's main environmental objectives? Select all that apply.

- Electricity consumption reduction.
- Water consumption reduction.
- Land use reduction.
- Greenhouse gas emissions reduction.
- Other gases emissions reduction.
- Waste production reduction.
- Use of raw materials reduction.
- Substances releasing into the soil reduction.
- Other

7. S2.2 Does the company have any of the following areas/departments? Select all that apply.

- Environmental Management.
- Leadership.
- Planning of environmental objectives.
- Environmental risk and opportunities.

- Resources and environmental support.
- Communication.
- Operation and environmental control.
- Emergency response.
- Monitoring, analysis, and evaluation of EMS performance.

8. S2.3 What is the company's internal communication strategy? Select all that apply.

- Website.
- Email.
- Social media (Facebook, Instagram etc.).
- Newsletters.
- Internal staff site.
- Other

9. S2.4 What is the company's external communication strategy? Select all that apply.

- Website.
- Social media (Facebook, Instagram, etc).
- Newsletters.
- Advertisement.
- Marketing campaigns.
- Other

10. S2.5 Does the company disclose environmental information to any stakeholders? Select all that apply.

- Clients.
- Ecology associations.
- Public administrations.
- Suppliers.
- Shops.
- Other

11. S3.1 Has the organization clearly identified the Environmental Director in the company? Mark only one oval.

- Yes.
- No.

12. S3.2 How often does the senior management review the organization's environmental management system? Mark only one oval.

- At least every six months.
- Annually.
- Over a year.
- Never.

13. S3.3 Has the company established processes to achieve annual environmental results? Mark only one oval.

- Yes.
- No.

14. S4.1 Has the company established an environmental policy? Mark only one oval.

- Yes.
- No.

15. S4.2 How does the company communicate and/or promote its environmental policy? Select all that apply.

- Website. Newsletter. Social Media. Advertisement.
- E-mail promotional. Marketing campaigns.
- Courses
- None of these
- Other

16. S4.3 Does the company's environmental policy include any of these commitments? Select all that apply.

- Reduce use of water.
- Reduce use of fossil combustible.
- Control of electricity use.
- Reduce of fertilizers and pesticides use.
- Reduce of gas emissions.
- Increasing land use efficiency.
- Improvement in packaging (glass bottles).
- Improvement in wines distribution.

17. S4.4 What aspects of the life cycle are included in environmental policy? Select all that apply.

- Environmental impacts of the supply chain.
- Environmental impacts of product use.
- Environmental impacts of waste generation.

18. S3.4 Who is responsible for environmental management? Mark only one oval.

- Owner
- o General Manager
- o Environmental Manager
- o Administrative Manager
- o Vineyard Director
- o Executive Director
- Other:

19. S5.1 Considering that wineries have a high energy consumption, what actions or measures does the company take to reduce the environmental impact?

20. S5.2 Wineries generate a lot of solid waste which, once disposed of, has a high environmental impact. How is this high amount of waste managed?

21. S5.3 Wineries generate gases that are usually impregnated with fruit or machinery. What processes should be in place to reduce these emissions and therefore generate less impact?

22. S6.1 Has the company prepared plans to prevent or mitigate negative environmental impacts resulting from emergency situations? Mark only one oval.

- Yes.
- No.

23. 6.2 If so, which environmental emergency is the company prepared for? (Select one or more). Select all that apply.

- Fire
- Water uncontrolled discharge with cleaning product or organic matter residues.
- Water drains with chemical contaminants.
- Landfilling of waste and/or abandoned waste.
- Leakage of dangerous substances.
- Other

24. S6.3 Does the company periodically review planned response actions for emergency situations? Mark only one oval.

- At least every six months.
- Annually.
- Over a year.
- Never.

25. S7.1 Does the organization have documented information to demonstrate that monitor, measure and evaluate its environmental performance? Mark only one oval.

- Yes.
- No.

26. S7.2 How does the organization record information to demonstrate that it evaluates the effectiveness of its environmental management system? Select all that apply.

- Data records.
- Reports.
- Technical Instructions.
- Procedures.
- None of these.
- Other.

27. S7.3 How often does the company create and update documented information consistent with its environmental management system? Mark only one oval.

- At least every six months.
- Annually.

- Over a year.
- Never.

28. S9.2 Does the company have legal requirements from government bodies or other relevant authorities in relation to environmental impacts? Mark only one oval.

- Yes.
- No.

29. S8.1 Is training offered to staff on environmental management systems? Mark only one oval.

- Yes.
- No.

30. S8.2 If so, how often do staff take these environmental trainings? Mark only one oval.

- At least every six months.
- Annually.
- Over a year.
- Never.

31. S8.3 How many workers have already undergone environmental management training? Mark only one oval.

- Less than 25%
- Between 25 - 50%
- Between 50 - 75%
- More than 75%

32. S9.3 What method does the organization use to carry out risk analysis? Mark only one oval.

- Quantitative method
- Qualitative method
- None

33. S9.4 What method does the organization use to perform the opportunity analysis? Mark only one oval.

- Quantitative method
- Qualitative method
- None

34. S10.1 Has the company certified its EMS with ISO 14001:2015? Mark only one oval.

- Yes.
- No.