frontiers | Frontiers in Sustainable Food Systems

TYPE Review
PUBLISHED 08 October 2024
DOI 10.3389/fsufs.2024.1437872

OPEN ACCESS

EDITED BY
Marzia Ingrassia,
Università degli Studi di Palermo, Italy

REVIEWED BY
Eleonora Crenna,
University of Applied Sciences and Arts of Western Switzerland, Switzerland
Luca Lombardo,
Council for Agricultural Research and Economics, Italy

*CORRESPONDENCE
Cátia Brito
✉ cvqbrito@utad.pt

RECEIVED 27 May 2024
ACCEPTED 27 September 2024
PUBLISHED 08 October 2024

CITATION
Brito C, Pereira S, Martins S, Monteiro A, Moutinho-Pereira JM and Dinis L (2024) Strategies for achieving the sustainable development goals across the wine chain: a review.
Front. Sustain. Food Syst. 8:1437872.
doi: 10.3389/fsufs.2024.1437872

Strategies for achieving the sustainable development goals across the wine chain: a review

Cátia Brito[1,2]*, Sandra Pereira[1,2], Sandra Martins[1,2], Ana Monteiro[1,2], José Manuel Moutinho-Pereira[1,2] and Lia Dinis[1,2]

[1]CITAB–Centre for the Research and Technology of Agro-Environmental and Biological Sciences, University of Trás-os-Montes and Alto Douro (UTAD), Vila Real, Portugal, [2]Inov4Agro–Institute for Innovation, Capacity Building and Sustainability of Agri-Food Production, University of Trás-os-Montes and Alto Douro (UTAD), Vila Real, Portugal

In the face of escalating climate change impacts, the Sustainable Development Goals (SDGs) set forth by the United Nations present a comprehensive blueprint for achieving a better and more sustainable future for all. The wine industry, with its extensive global reach and significant economic impact, holds a unique position to contribute toward these goals. This review examines how the wine industry can, directly and indirectly, support all 17 SDGs through a multidisciplinary approach, incorporating extensive literature analysis. The study explores the alignment of wine industry practices with the SDGs across three key pillars: social, environmental, and governance goals. Social initiatives focus on enhancing livelihoods, food security, fair and safe working conditions, inclusive and ethical development among the workers and communities, education, and economic growth. Environmental efforts emphasize reducing the industry's carbon footprint, conserving water, improving water and energy use efficiency, improving grapevine resilience against adverse environmental conditions, minimizing pollution, protecting biodiversity, creating more sustainable cities, and promoting moderate wine consumption. Governance goals highlight the importance of regulatory frameworks, wine industry standards, and stakeholder engagement in promoting sustainable, responsible and ethical practices, contributing to effective partnerships and institutional capacity. Conclusions highlight the wine industry's commitment to sustainability as a catalyst for positive change, demonstrating that profitability and environmental stewardship can coexist. Future perspectives call for enhanced collaboration, research, education, supportive policies, robust monitoring, and equality initiatives. By embracing sustainable practices, the wine industry can play a vital role in advancing the global agenda for a more equitable, resilient, and sustainable future.

KEYWORDS

climate change, viticulture, wine industry, sustainability, green strategies

1 Introduction

In recent decades, the scientific community has sounded alarms about the escalating threat of climate change and its far-reaching consequences for our planet. The Intergovernmental Panel on Climate Change's (IPCC) sixth assessment report (AR6) unequivocally confirms the wide-ranging impacts of climate change across every region worldwide (IPCC, 2023). Projections indicate a global temperature rise of at least 1.5°C within the next two decades,

with disproportionate effects on regional climates, including shifts in precipitation patterns. These changes are exacerbating extreme weather events such as heatwaves, droughts, floods, and storms, highlighting the fragility of our planet. As the United Nations (UN) Secretary-General António Guterres said, the IPCC Working Group report is a "code red for humanity," underscoring the urgent need for collective action to mitigate climate change (UN, 2024b). Addressing these challenges requires a profound shift in how humanity produces, processes, and consumes food and agricultural products, and this transformation must occur within a notably shorter timeframe than ever before. In this way, in 2015 the UN proposed the Sustainable Development Goals (SDGs) (UN, 2024a; UNDP, 2024). The SDGs represent a universal call to action, encompassing 17 global objectives addressing pressing issues like poverty, inequality, climate change, and environmental degradation. They serve as a comprehensive framework guiding international efforts toward economic, social, and environmental sustainability by 2030 (Sachs, 2012).

The agricultural sector, including viticulture, plays a dual role as a significant contributor to greenhouse gas emissions and as one deeply affected by climate change. Consequently, it bears the responsibility to adapt to the challenges of climate change and take proactive actions to mitigate its effects. The wine industry holds significant economic, social, and environmental importance, contributing billions of euros/dollars to international trade and the economies of both traditional and emerging wine-producing nations (Dodds et al., 2013). Wine production is a globally distributed industry, with significant regional variations in climate, geography, political environment, and socio-economic conditions. The key wine-producing regions include Europe, the Centre-South EU region, including countries such as France, Italy, and Spain; North America, the United States, particularly California; South America, Argentina and Chile; Africa, mainly South Africa; and Oceania, Australia and New Zealand (Puga et al., 2022).

From a societal standpoint, wine has evolved into an integral aspect of culture, offering enjoyment, leisure, and a diverse range of social interactions (Bandinelli et al., 2020). Simultaneously, wine serves as a source of pride for numerous local communities, playing a crucial role in employment generation and contributing to cultural development (Marco-Lajara et al., 2022). Wine-producing regions face unique challenges, including increased temperatures, declining precipitation and increased evapotranspiration, leading to diminished soil moisture levels, and the proliferation of pests and diseases, all of which can profoundly affect yields, grape quality and wine production (Mira de Orduña, 2010). Moreover, the loss of biodiversity and soil health further threatens the resilience of agricultural ecosystems. In response to these challenges, the adoption of sustainable agricultural practices becomes imperative, offering viable solutions to mitigate environmental impacts associated with conventional agricultural practices (Foguesatto et al., 2020), while enhancing resilience to climate change.

There is a clear call for a fresh sustainable development agenda that fosters rapid progress in both developing and developed nations, with equal emphasis on social, economic, and environmental considerations. This agenda should be transformative, encouraging innovative thinking and developmental models, rather than perpetuating the *status quo*. It must be ambitious, inspiring action from individuals of all ages and across all levels of society (Atkin et al., 2011). According to the International Organization of Vine and Wine (OIV), a sustainable grape and wine sector involves a holistic approach that addresses global strategies in production and processing. This includes ensuring economic sustainability for both industry structures and the involved territories, producing high-quality foods, practicing precision viticulture, considering environmental risks, ensuring product safety and consumer health, and preserving heritage, cultural, and ecological elements (OIV, 2004). Aligned with this vision, the 2030 agenda has sparked increased attention within the wine industry, as it is anticipated to play a significant role in achieving the SDGs (Gomes et al., 2021). The industry is also recognized as a key player in sustainable development; the wine industry has increasingly embraced measures to minimize its environmental footprint, including renewable energy adoption, reduced pesticide and fertilizer usage, enhanced water quality, and foster biodiversity (Maicas and Mateo, 2020; Fuentes-Fernández et al., 2022; Gadoury et al., 2023).

In light of these considerations, this review aims to examine how the wine industry can directly or indirectly contribute to achieve each of the 17 SDGs. By adopting a multidisciplinary approach, we seek to elucidate the sector's role in proceeding climate neutrality and fostering sustainable development on a global scale. Additionally, we aim to provide insights that can drive further research and practical applications within the field, as well as inform future strategies and initiatives aimed at promoting a more sustainable and resilient wine industry.

The main research approach used in this study is a critical and extensive analysis of literature and knowledge from multiple disciplines related to this business sector. This approach incorporates sources such as scientific and technical manuscripts, books, institutional and technical reports, institutional web-sites and press releases.

2 Article aligning the wine chain industry with the sustainable development goals

This review is structured by grouping the Sustainable Development Goals into social, environmental, and governance categories, each representing a crucial aspect of fostering a sustainable and resilient wine industry. These goals support the three pillars of sustainable development: economic, environmental, and social. Within each category, we present a comprehensive analysis of measures and case studies illustrating how the wine industry can align its practices with the SDGs.

The Social Goals section delves into objectives related to human well-being, equity and social inclusion within communities where vineyards operate. We examine initiatives aimed at improving livelihoods, enhancing food security, promoting fair and safety work conditions and inclusive growth among vineyard workers and local populations. This section includes the SDGs 1 (No Poverty), 2 (Zero Hunger), 3 (Good Health and Well-being), 4 (Quality Education), 5 (Gender Equality), 8 (Decent Work and Economic Growth), 9 (Industry, Innovation and Infrastructure), 10 (Reduced Inequalities), and 16 (Peace, Justice and Strong Institutions).

The Environmental Goals section addresses the paramount importance of environmental sustainability in mitigating the impacts of climate change and preserving natural resources. We investigate strategies employed by the wine industry to reduce its carbon

footprint, conserve water, protect biodiversity, and minimize pollution. We showcase innovative approaches and best practices that promote environmental management across the entire wine production chain. This section includes the SDGs 6 (Clean Water and Sanitation), 7 (Affordable and Clean Energy), 11 (Sustainable Cities and Communities), 12 (Responsible Consumption and Production), 13 (Climate Action), 14 (Life Below Water), and 15 (Life on Land).

The Governance Goals section demonstrates that effective governance mechanisms are essential for achieving all SDGs. We explore the role of regulatory frameworks, industry standards, and stakeholder engagement in promoting responsible business practices and ethical conduct. By analyzing governance structures and policy interventions, we identify opportunities to strengthen institutional capacity and enhance the industry's contribution to sustainable development. This section includes the SDG 17 (Partnerships for the Goals).

2.1 Social goals

2.1.1 Poverty and hunger eradication (SDGs 1 and 2)

The SDG 1, "No Poverty," is focused on the eradication of poverty worldwide, ensuring access to basic resources and services, promoting economic opportunities for all and supporting threatened communities (UN, 2024a; UNDP, 2024). Targets 1.1 and 1.2 address income poverty, while targets 1.3–1.5 aim to reduce vulnerability through social protection systems. Poverty encompasses various dimensions such as nutrition, health, education, and decent work (Mainali et al., 2018; UN, 2024a), making SDG 1 a cross-cutting goal intersecting with other SDGs. Indeed, achieving this SDG requires progress in targets related to access to clean energy (SDG 7), clean water and sanitation (SDG 6), and food security and nutrition (SDG 2) (Mainali et al., 2018).

Similarly, the SDG 2, "Zero Hunger," aims to eradicate hunger and malnutrition, ensuring that all people have access to nutritious and sufficient food. This goal involves promoting sustainable agricultural practices, rural development, and supporting small-scale farmers (UN, 2024a; UNDP, 2024). This SDG comprises eight targets, five focusing on food security and agricultural sustainability (2.1–2.5), and three on market measures (2a–2c) to boost agricultural investments and reduce market imbalances (FAO, 2016; Gil et al., 2019).

Studies have highlighted a synergistic and robust relationship between SDG 1 and SDG 2 (Mainali et al., 2018; Fonseca et al., 2020), as universal access to safe, nutritious and sufficient food is intrinsically linked with poverty eradication (Mollier et al., 2017). According to the UN, severe poverty and hunger disproportionately affect rural populations in marginal agricultural areas (Calicioglu et al., 2019; Ahmadzai et al., 2022). Addressing these issues extends beyond agriculture, including social protection policies and safety nets to eliminate food insecurity (Calicioglu et al., 2019).

Furthermore, achieving these goals demands localized solutions considering sectorial and regional aspects (Martins et al., 2019). To combat poverty and hunger, promoting inclusive economic growth, especially for marginalized communities, is crucial. This involves investments in transferring assets, technology, and inputs like small livestock, fertilizers, pest control solutions, and improved seeds, with the aim of boosting farmer productivity, and enhancing food security, thus alleviating structural constraints faced by the impoverished (Rusere et al., 2019).

In the wine-producing regions, this can be achieved by promoting initiatives that support the local farmers, improving their market access and providing training and funding for sustainable cultivation. Moreover, the implementation of strategies to restore the gap between producers and consumers, can facilitate economic integration and reduce inequalities in accessing global markets. Several regional and international organizations are developing programs, certification schemes, and initiatives to support winegrowers by providing tools and guidance for adopting sustainable practices (Martins et al., 2019). This is the case of the California Sustainable Winegrowing Program, an initiative launched in 2002, consisting of an educational program which assists winegrowers and winemakers in adopting and implementing sustainable practices (Miller, 2016). The 2020 report of this program demonstrates improvements in over 2/3 of the vineyards and winery sustainable practice criteria when compared to the 2015 report (CSWA, 2020). In Australia, in 2009, a voluntary sustainability program for grape and wine producer's assistance was introduced, the Environmental Protection System, "Entwine" (WFA, 2009). In Portugal, in the Alentejo wine region, the Wines of Alentejo Sustainability Program was initiated, in 2013, to support the production and marketing of more sustainable wine, by providing tools and recommendations for using best practices (WA, 2024). According to the WA (2024) the results of the primary intervention (5-year period 2015–2019) show a continuous improvement in different areas of the sector, highlighting the management of diseases and pests, waste and energy and water (WA). On a global scale, OIV, the largest multilateral international organization in the wine sector, opted to standardize diverse approaches to prevent unfair competition and enhance communication and information exchange among stakeholders (Martins et al., 2019).

In addition to the previously mentioned voluntary certifications, a growing number of these programs have emerged worldwide in recent years. For instance, in the USA, programs such as Sustainability in Practice (SIP, 2024), Napa Green (NG, 2024) and Oregon Certified Sustainable Wine (OSB, 2024) have been introduced, while in the EU certifications like VIVA (VIVA, 2024), Terra Vitis (TV, 2024) and FAIR'N GREEN (FG, 2024) have been developed. The increasing availability of these initiatives has led to a significant rise in the conversion rate of vineyards to organic production. According to the OIV (2021), in 2019, 63 countries were involved in organic viticulture, with the certified organic vineyard surface area estimated at 454 kha, representing 6.2% of the world's total vineyard area. Moreover, between 2005 and 2019, the certified organic vineyard area grew at an average rate of 13% per year, while the non-organic vineyard area decreased by an average of 0.4% annually during the same period. This rapid growth can be attributed, in part, to the relatively recent adoption of certified organic viticulture (OIV, 2021). These data underscore the importance of implementing such certification programs to contribute to the achievement of the SDGs.

2.1.2 Good health and the well-being (SDG 3)

The SDG 3, "Good Health and Well-being," focuses on promoting healthy lives and well-being for individuals of all ages worldwide, by preventing and treating diseases, and ensuring access to quality healthcare services (UN, 2024a; UNDP, 2024). The wine industry can significantly contribute to SDG-3, particularly on targets 3.5,

"Substance abuse" and 3.6, "Road traffic" (UN, 2024a). Target 3.5 focuses on enhancing prevention and treatment measures for substance abuse, covering narcotic drug misuse and harmful alcohol consumption (UN, 2024a). Target 3.6 aims to reduce global fatalities and injuries from road traffic accidents (UN, 2024a). Currently, alcohol abuse is identified as a major contributor to over 200 diseases and injuries listed in the International Classification of Diseases, with at least 40 directly linked to alcohol consumption. Additionally, psychoactive substances impact brain function and often result in impaired driving, increasing the prevalence of road traffic accidents (Ferreira-Borges et al., 2020). To address these issues, several policies and legislations have been implemented to mitigate drink-driving and promote awareness about the dangers of excessive alcohol consumption. Responsible marketing strategies that promote moderate wine consumption are essential. Public education and awareness campaigns to inform consumers about the health risks associated with alcohol abuse and advocate for moderation as part of a healthy lifestyle should also be prioritized (Martínez-Falcó et al., 2023a). Moderate wine consumption, particularly red wine, has been associated with various potential health benefits, largely due to its rich content of antioxidants, such as resveratrol, anthocyanins, and catechins (Snopek et al., 2018). Research suggests that moderate intake—defined as up to one glass per day for women and up to two for men (Artero et al., 2015)—may contribute to cardiovascular health by improving cholesterol levels, reducing the risk of heart disease (Weiskirchen and Weiskirchen, 2016; Castaldo et al., 2019; Abreu et al., 2024), and enhancing blood vessel function. Furthermore, moderate wine consumption has been linked to a lower risk of certain cancers (He et al., 2008; Torres et al., 2023), improved cognitive function, and potentially longer lifespan (Artero et al., 2015; Weiskirchen and Weiskirchen, 2016). It may also reduce the risk of diabetes (Pastor et al., 2017), osteoporosis, neurodegenerative diseases (Weiskirchen and Weiskirchen, 2016; Pastor et al., 2017), and metabolic disorders (Weiskirchen and Weiskirchen, 2016; Pastor et al., 2017), while stimulating an immune response against inflammation (Weiskirchen and Weiskirchen, 2016). However, these benefits must be weighed against the risks of excessive alcohol consumption, which can lead to serious health issues, including liver disease, addiction, and an increased risk of cancer. To promote responsible consumption, the "Wine in Moderation" initiative was launched in 2008 by the European wine sector. This social responsibility program unites several wine organizations with the common goal of promoting moderate and responsible wine consumption as a cultural and social norm. The initiative involves more than 50,000 professionals in the wine sector across 15 countries, all committed to presenting, selling, and serving wine responsibly (Martínez-Falcó et al., 2023a; WineInModeration, 2024). In Sweden, Systembolaget AB, a state-owned alcohol retailer, is the only retail store allowed to sell alcoholic beverages with more than 3.5% alcohol by volume. Systembolaget's mission is to promote responsible alcohol consumption, focusing not on profit but on minimizing the harmful effects of alcohol in line with Sweden's restrictive alcohol policy.[1] By prioritizing public health, Systembolaget aims to reduce the negative impacts of alcohol consumption while allowing citizens to enjoy alcohol responsibly (Systembolaget, 2019).

2.1.3 Quality education, gender equality and inequalities reduction (SDGs 4, 5 and 10)

The SDG 4, "Quality Education," aspires to ensure inclusive and equitable quality education for all, as education is one of the most powerful and proven vehicles for sustainable development. Irrespective of gender or socio-economic background, everyone must have the opportunity to acquire the knowledge and skills necessary for personal development and participation in society (UN, 2024a; UNDP, 2024).

In the wine industry, there are numerous avenues through which the goal of SDG 4 can be supported. Workforce training and development programs play a crucial role, offering training in vineyard management, safety protocols, and skill enhancement, thereby enhancing productivity and facilitating personal growth and career advancement for workers. Collaboration with local communities and stakeholders is essential for promoting inclusive and sustainable viticulture. Wineries can sponsor educational events, offer vocational training, and support community projects, fostering a culture of continuous learning and development within the industry.

Beyond the workforce, the wine industry's educational efforts extend to the broader community. Wine tourism serves as an effective platform for raising awareness about sustainable practices and educating the public about the cultural and environmental aspects of winemaking. Through educational tours, tastings, and events, vineyards can showcase their sustainability efforts and educate visitors on vineyard management and wine production. This not only enhances consumer knowledge about wine production and characteristics but also can enhance their appreciation, preferences and informed choices. In fact, research among different regions suggests that education, such as wine courses, enhance the capacity to discern nuances among wines and shift preferences toward red, pink and white wine, suggesting a link between knowledge and preference (Charters, 2006; Taylor et al., 2008).

In line, the wine industry is increasingly involved in research projects that include Living Labs-collaborative platforms that bring together citizens, research organizations, companies and government agencies. These labs enable active user involvement, education and increased awareness about the sector's needs and sustainability. For example, the ongoing ECOSPHEREWINES project [INTERREG SUDOE (S1/2.7/E0010)] focuses on improving landscapes linked to vine cultivation, a fundamental economic and tourist resource in the SUDOE (South-West Europe) area,[2] particularly in inland territories, affected by depopulation and aging, where the preservation of natural and environmental capital is crucial for rural communities as it is a source of wealth. Similarly, the European LivingSoiLL-Healthy Soil to Permanent Crops Living Labs (HORIZON-MISS-2023-SOIL-01) focuses on co-creating, co-implementing and co-testing solutions to improve healthy soils and ecosystem services for future generations. Moreover, several organizations and companies within the wine industry are dedicated to educational outreach. The "Association of Wine Educators – AWE" in the UK (AWE, 2024), for instance, aims to inform, educate and inspire the general public about wine through various initiatives such as club/society tastings, wine courses, wine tours and public/trade wine shows (AWE, 2024). Similarly, wine

1 https://www.systembolaget.se/

2 https://4.interreg-sudoe.eu/PRT

companies like Symington Family States in Portugal (Symington, 2024) and Santa Barbara Wine Tours and Tasting in California (Santa Bárbara, 2024) organize wine tastings and visits through the vineyards, emphasizing the importance of terroir, environmental challenges and the local wines typicity.

Despite these potential contributions, the wine industry still faces challenges in achieving quality education. Limited access to educational resources, language barriers and insufficient formal training can hinder workforce development efforts. Many wine regions lack nearby educational institutions and the financial means to afford training resources. Language barriers prevent non-native speakers from fully understanding educational materials, leading to communication gaps. Additionally, insufficient formal training means workers often miss out on standardized skills, ongoing professional development, and the ability to manage vineyards effectively. Addressing these challenges requires the stakeholders to collaborate with educational institutions and governments to provide the necessary resources and infrastructure. Seasonal work patterns and financial limitations can impede continuous education for workers. Developing flexible, cost-effective training and multilingual programs to ensure all workers can benefit, is essential to overcoming these challenges. Keeping up with technological advancements is crucial for industry competitiveness. Integrating modern technology into training programs ensures that workers stay updated with industry innovations. A case study in South Africa highlights progress in vineyard quality management but persisting challenges in worker training, mobility, and personal development is hindering industry competitiveness. The study shows that overcoming challenges like limited mobility in the labor market and health issues among workers requires a holistic approach that integrates technical training with personal development initiatives such as literacy training, healthcare and improved housing (Vink et al., 2010).

The SDG 5, "Gender Equality," is dedicated to achieving gender equality and empowering all women and girls. The goal seeks to eliminate discrimination, violence, and harmful practices based on gender. Also, it envisions a world where women and girls have equal opportunities in all aspects of life, including education, employment, participation in decision-making processes and leadership (UN, 2024a; UNDP, 2024).

While the SDG 5 emphasizes the global imperative of achieving gender equality, the viticulture industry presents a compelling case study where persistent gender disparities continue to challenge progress toward this goal. In the viticulture context, the industry has historically been male-dominated, with positions such as winemakers, vineyard owners, and top executives largely occupied by men. Women continue to face significant underrepresentation in leadership roles, encountering challenges such as gender bias and unequal opportunities. The undervaluation of women's roles in viticulture is influenced by hereditary land property systems and societal expectations. Patrilineal inheritance has historically excluded women from landownership and decision-making, perpetuating gender norms. Social expectations confine women to domestic roles, restricting their access to resources and opportunities in farming. Nonetheless, women have always been pivotal contributors to agriculture, playing essential roles in food production and family sustenance (Mennell, 1992; Counihan, 2004).

Research by Benedetto and Corinto (2015) highlights women's enduring contributions to sustainability within the Italian wine industry. Despite starting with fewer resources and technical skills, women have exhibited remarkable adaptability and innovation in farm management, ensuring the long-term viability of their businesses. This shift is particularly noteworthy given the historical context of rural depopulation and the migration of Italians to urban areas and non-agricultural industries during the mid-twentieth century. Case studies, such as Sogrape, a family-owned wine company based in Portugal, provide insight into gender dynamics within the industry. In 2017, Sogrape's workforce comprised 59% men and 41% women, reflecting the company's dedication to fostering a diverse workforce. However, gender-based wage disparities persisted, with women earning wages 11% lower than their male counterparts on average, highlighting the existence of a gender pay gap within the organization. The absence of female employees in administrative roles during this period raises questions about gender dynamics across various job roles within Sogrape (Teixeira, 2022). Despite efforts, Portugal continues to grapple with challenges such as the prevalence of illegal fixed-term contracts and wage disparities between genders in the labor market (Teixeira, 2022).

Efforts within the wine industry aim to address these disparities and cultivate a supportive environment for women, fostering innovation and diverse perspectives in winemaking. Despite a longstanding imbalance, with approximately 82% of winemakers globally being men and only 18% women (Mennell, 1992; Counihan, 2004), there are active initiatives aimed at rectifying this disparity and promoting gender equality within the sector. Historically, women in the wine industry have faced significant challenges, particularly in entrepreneurship, where they often operate smaller ventures with limited capital (Benedetto and Corinto, 2015). Most of the research about women's roles in the wine industry is recent and scarce (Livat and Jaffré, 2021). Although there has been progress over the past two decades, with women increasingly emerging in various roles within the industry (Livat and Jaffré, 2021), gender inequality remains a pressing issue. For instance, statistics from 2018 to 2019 indicate that women's total entrepreneurial activity in the leading wine-producing countries is generally below 20%, with Italy showing the lowest rate at 3% and Chile the highest at 21% (Elam et al., 2019). These figures underscore the ongoing need for initiatives that promote gender equality and support women in overcoming barriers to entry and success in the industry. It is also crucial to recognize the regional variations in gender inequality within the global wine industry. According to the Gender Inequality Index (GII) (United Nations, 2019), there is a significant disparity among the most prominent wine-producing countries. France, Italy, and Spain are noted for having lower levels of gender inequality, while countries such as South Africa, Argentina, and Romania exhibit higher levels of inequality. This suggests that efforts to promote gender equality in the wine industry must be tailored to the specific socio-economic and cultural contexts of different regions. Overall, while progress has been made, the wine industry still requires sustained and context-sensitive efforts to achieve gender equality, ensuring that women have equal opportunities to thrive and contribute to this dynamic sector.

The SDG 10, "Reduced Inequalities," is committed to reducing inequality within and among countries, taking into consideration social, economic, and political disparities. This goal intends to ensure more equitable sharing of development benefits, providing assistance where it is most needed, and facilitating safe migration and mobility of people (UN, 2024a; UNDP, 2024).

In parallel with efforts to address disparities in education and gender, social inequality is a significant concern within viticulture. Some inequalities persist, and new ones are emerging in the wine industry. Nowadays, many wine-producing regions rely on migrant laborers who often face low wages and hazardous working conditions. In California's Central Valley, for example, a significant portion of the state's renowned wine grapes is harvested by migrant workers (Velasquez, 2018; Ornelas-Higdon, 2021). Similarly, in Europe's wine-producing areas, migrant workers from North Africa and Eastern Europe are frequently employed in vineyards and wineries (ANSA, 2019; Gore et al., 2021; Guidi and Berti, 2023). These migrants often face poor working conditions such as forced labor or earning minimum wage or less, long working hours, exposure to extreme weather, lack of proper safety equipment, inadequate training on the use of machinery, and unsafe and unsanitary housing. These factors collectively contribute to heightened health risks and safety hazards, as detailed in a human rights impact assessment (HRIA) report of Systembolaget's Italian wine supply chains (Gore et al., 2021). Furthermore, many agricultural fatalities resulting from accidents involving machinery are likely exacerbated by these factors. This assessment was conducted in cooperation with OXAM, a British-founded confederation of 21 independent NGOs focused on "fighting inequality to end poverty and injustice",[3] and the Systembolaget AB company previously referred, which is also one of the world's largest buyers of alcoholic beverages in the world. In Italy, a study from 2018 illustrates how the exploitation of migrants is used to cut costs and increase the competitiveness of the wine sector. During the 2011 post-Arab Spring migration wave, approximately 64,000 migrants arrived on the southern coast of Italy. Winemakers in regions like Sicily and Puglia took advantage of this cheap, undocumented labor through *caporalato*, a widespread system of illegal recruitment of underpaid farm labor managed by Italian agrimafias. Labor productivity in these regions' wine industries was estimated to have increased by about 11% on average in 2011 and 2012, corresponding to around 10 million unreported work hours, or the equivalent of 21,000 full-time employees, each year (Seiferd and Valente, 2018).

These issues indicate that there is ample room for the industry to improve and contribute to social and economic equity in this field.

The previously referred report by Gore et al. (2021) is a valuable analysis that aims to address these pressing issues. It identifies several severe human rights violations within the Italian wine supply chain and recommends actions such as improving access to grievance mechanisms, revising recruitment practices, addressing women's rights, and ensuring that workers have written contracts. Implementing these recommendations will require time, dialogue with stakeholders, and political engagement to find practical solutions and provide necessary training. According to the authors (Gore et al., 2021), "this assessment can be seen as part of Systembolaget's efforts to undertake more robust human rights due diligence processes that go beyond audits," serving as a strong example of how to stand at the forefront of sustainable development. A notable initiative in this regard took place in France, where the renowned Château Pédesclaux, located in the Grands Crus du Bordelais wine region, partnered with Ovale Citoyen (an association of former rugby professionals that uses rugby and other sports to promote team-building and inclusion) to offer seasonal jobs and training in the wine industry to refugees (Schmitt and Thompson-Gorry, 2021). Particularly when practiced in specific regions, viticulture can act as a catalyst for social and regional equity. Through the creation of local employment opportunities, viticulture not only mitigates economic and regional disparities but also sustains community livelihoods, thereby ensuring intergenerational prosperity. Wine cooperatives can also implement community development programs aimed at reducing inequalities within local communities. For instance, they could establish educational initiatives targeting marginalized groups, such as providing scholarships for underprivileged children or offering vocational training programs for unemployed individuals. In line, the wine industry has seen a growing number of initiatives aimed at fostering diversity and inclusion, particularly by supporting BIPOC (Black, Indigenous, and People of Color) students and aspiring hospitality professionals. These programs often include scholarships, mentorships, and other resources designed to help underrepresented groups enter and thrive in the wine industry (Brown, 2021). One notable example is the "Black Wine Professionals" initiative, established by the renowned wine writer Julia Coney. This initiative serves as a database for BIPOC writers, speakers, educators, sommeliers, retailers, importers, distributors, buyers, wine directors, and marketers. Beyond serving as a networking platform, Black Wine Professionals also provides educational tools and mentoring. In collaboration with Champagne Laurent-Perrier USA, the organization recently awarded scholarships to five individuals to pursue the Wine Scholar Guild's Champagne Master-Level certification courses (Brown, 2021). Another impactful initiative is "Wine Empowered," co-created by beverage director Victoria James. This program offers tuition-free wine education to women and minorities, covering the fundamentals of wine education. Each student also receives a one-year membership to GuideSomm, which provides additional educational resources and support (Brown, 2021). The "Delicato Family Wines Winemaker Scholarship for BIPOC" is another significant effort to improve diversity and inclusion in the wine industry. This scholarship provides full tuition, living expenses, professional development, and industry experience for students planning to study viticulture and enology at one of several prestigious institutions, including the University of California, Davis; California Polytechnic State University; and California State University, Fresno. By offering these comprehensive support packages, the scholarship aims to empower a new generation of diverse winemakers, contributing to a more inclusive and equitable wine industry (Brown, 2021).

Moreover, collaboration among small grape and wine producers can enhance their market position, enabling collective action to overcome shared challenges and uplift overall economic conditions. Wine cooperatives are an effective form of social entrepreneurship. In addition to benefiting their members, they serve as important vehicles for mobilizing local resources and fostering cooperation among citizens, organizations, and political representatives. Then these cooperatives promote community development and play a vital

3 www.oxfam.org

role in the societal advancement process (Figueiredo and Franco, 2018; Marques and Teixeira, 2023). By providing training, improving working conditions, and promoting gender and remuneration equality the measures discussed in this SDG can also be linked with the goals outlined in SDGs 4, 5 and 8.

2.1.4 Functional and resilient infrastructures, sustainable industrialization and economic growth endorsing inclusive and decent work (SDGs 8 and 9)

The SDG 8, "Decent Work and Economic Growth," aims to promote sustained, inclusive, and sustainable economic growth, generating productive employment and decent work for all. Thus, contributing to the well-being and prosperity of individuals and communities (UN, 2024a; UNDP, 2024).

Based on three empirical case studies of settlements in different wine regions in Hungary, Tomay and Tuboly (2023), conclude that the economic success of winemaking settlements is due either to lifestyle entrepreneurs moving in or to the strength of the locally bounded community. The wine industry emerges as a vital contributor to this goal, leveraging viticulture to drive local employment creation, mitigate economic and regional disparities, and facilitate training and capacity-building initiatives within communities.

Fair pricing and transparency in the wine supply chain are crucial for promoting decent work and economic growth. When fair prices are adopted, all actors in the wine supply chain can receive fair compensation and benefit from equitable income distribution. This can lead to improved livelihoods, reduced income disparities, and diminished economic inequalities. Additionally, combating undeclared work further supports SDG 8 by ensuring that all workers are protected by labor laws, receive fair wages, and are included in social security systems. This commitment promotes productive employment, decent work conditions, and reduced corruption within the industry, contributing to economic growth.

Furthermore, by enhancing the performance of wine cooperatives, embracing market-oriented strategies and actively participating in global markets, promoting exports underscores the industry's commitment to economic growth and poverty reduction (Mozas-Moral et al., 2021). Integrating bottling operations with a focus on end-market orientation presents a strategic opportunity for wine companies to enhance performance and market competitiveness, ultimately contributing to economic expansion (Garcia et al., 2012). A prime example of this is Mateus Rosé wine launched in 1942. Its success is largely attributed to its distinctive bottle design, inspired by World War I canteens. This unique shape, compact and easily recognizable, was a strategic marketing move that ensured the bottle stood out on shelves, often placed at eye-level and within easy reach of consumers. This design, paired with the wine's approachable flavor, helped make Mateus Rosé the best-selling Portuguese wine worldwide, turning it into an iconic brand (CMB, 2023).

Despite the industry's significant contributions to achieving SDG 8, challenges persist, as evidenced by recent research in Australia highlighting the impact of technological advancements in grape production, which diminishes the demand for labor per hectare (McFarlane et al., 2013).

Moreover, by prioritizing fair labor practices, ensuring safe working conditions, reducing corruption within the industry and promoting financial stability, the wine sector continues to drive job creation and sustainable economic development globally, aligning also with SDGs 1, 10 and 16.

The SDG 9 "Industry, Innovation and Infrastructure" strives to establish resilient infrastructure, foster inclusive and sustainable industrial practices, and catalyze scientific inquiry and technological innovation (UN, 2024a; UNDP, 2024).

Viticulture plays a crucial role in infrastructure development, particularly in rural areas, where vineyards often serve as hubs for economic activity. Establishing and maintaining vineyards and winemaking processes necessitates the development of essential infrastructure, such as roads, irrigation and winery wastewater treatment systems, reliable transport and storage facilities. These infrastructure projects not only support viticulture but also benefit local communities by improving accessibility, facilitating transportation of goods, and enhancing overall connectivity. Modernizing winery infrastructure for sustainability enhances energy efficiency, minimizes waste, and significantly advances the industry's resilience and sustainability, as discussed in SDGs 6 and 7.

Furthermore, the wine industry's commitment to sustainable practices and technological innovation aligns with the principles of sustainable industrialization. Pilot projects conducted in Cyprus and Italy demonstrated the effectiveness of the integration of digital labeling and smart farming solutions in reducing the environmental footprint of wine production. For instance, in Cyprus this integration led to a substantial 75% reduction in pesticide usage and an 8% enhancement in perceived quality of wine. In Italy, it resulted in a 33% decrease in greenhouse gas emissions and a 5% improvement in intrinsic product quality (Kasimati et al., 2024). Smart viticulture technologies, such as GPS, IoT systems, drones equipped with multispectral devices, weather and plant physiology sensors, revolutionizes vineyard management practices, optimizing soil and plant health (Carneiro et al., 2022; Gonçalves et al., 2022; Fonseca et al., 2024). Concurrently, genetic studies advance the development of disease-resistant grape cultivars, reducing reliance on pesticides (Salmon et al., 2018; De Lorenzis et al., 2022), while embracing sustainable methods like organic farming and renewable energy sources further reinforces environmentally conscious approaches (Jindo et al., 2022). Technological progress in winemaking not only facilitates the creation of high-quality wines but also offers solutions for confronting climate change-related challenges, such as increased grape sugar concentrations that result in elevated alcohol levels, lower acidities and modification of varietal aroma compounds (Mira de Orduña, 2010). Presently, methods such as wine acidification and techniques for dealcoholisation are at the forefront of research efforts (Sam et al., 2021; Payan et al., 2023).

By integrating environmentally friendly methods such as avant-garde agricultural practices and sustainable technologies, organic farming and renewable energy sources, as discussed in SDGs 6, 7 and 13, farms and wineries minimize their ecological footprint while promoting resource efficiency and conservation. Research and development initiatives play a pivotal role in refining vineyard management practices and wine production techniques, fostering sustainability and new products development. Then,

embracing technological advancements in vineyard management and winemaking processes, and diversifying products is crucial for enhancing efficiency, reducing environmental impact, and driving industry-wide innovation.

2.1.5 Peace, justice and creation of responsible institutions (SDG 16)

The SDG 16, "Peace, Justice and Strong Institutions," is focused on promoting peaceful, just, and inclusive societies, by reducing violence, providing access to justice for all, promoting human rights and effective and inclusive governance (UN, 2024a; UNDP, 2024).

The vine and wine sector, while transversal to various industries, can take initiatives promoting transparency, responsibility, ethical conduct, and inclusive decision-making across all levels. To align with the principles of SDG 16, regulations and financial support should be implemented to encourage or mandate the adoption of fair-trade practices within this sector. This not only guarantees fair remuneration for grape growers and laborers but also supports ethical treatment, contributing to economic justice and safeguarding the basic human rights of those involved in the viticulture process. Moreover, the vine & wine sector can be a source of economic development, particularly in regions affected by conflict or poverty. The collaborative nature of winemaking adopts teamwork among individuals from diverse backgrounds, inherently contributing to building inclusive societies. Furthermore, the Farm to Fork strategy (EC, 2020) claims that food fraud jeopardizes the sustainability of food systems. To address this concern, wine-growing companies must proactively adopt practices ensuring not only food safety (claimed by SDG 2) but also fair commercial practices.

South Africa and Ukraine can serve as case studies to illustrate those subjects. South Africa is still a developing country, despite the abundant goods, natural resources, and notable advancements in industry and manufacturing. This is primarily attributed to substantial imports, emphasizing the need for South Africa to enhance its agricultural sector (Bakari, 2017). Analyzing the South African wine industry, Vink et al. (2010, 2012) highlighted a substantial contribution to the country's overall economy. The industry experienced a boom period post-apartheid (1994), marked by rapid emergence in wineries, wine exports becoming the largest single agricultural export, and employment growth, in contrast to the general decline in agricultural employment. However, challenges have threatened the sector development, particularly affecting small-scale farmers. Many wineries are small, climate change poses new investment challenges (addressed in SDG 13), and farm workers are often rudimentarily educated, struggling to produce high-quality grapes. Issues extend to social and health dimensions. A significant portion of the labor force remains illiterate and faces pathologies like alcohol abuse, tuberculosis, and HIV/AIDS (issues addressed by SDGs 3 and 4). Social development is constrained, with worker training mainly informal and lacking formal recognition, limiting mobility in the labor market. Even when workers have access to conventional labor rights, interpersonal dynamics, characterized by paternalistic or adversarial attitudes, frequently undermine self-esteem and fail to inspire strong motivation for learning, being necessary to promote more responsible industries. Consequently, within the South African context, addressing these challenges requires more than technical skills training and competitive salaries. Vink et al. (2010, 2012) claimed that initiatives for personal and human development, such as literacy training, basic healthcare, and access to decent housing, are imperative to foster a just and inclusive society. According to Nair et al. (2023), South Africa has been responding to growing demands for sustainability by creating a variety of programs and initiatives. The Wine and Agricultural Ethical Trading Association (WIETA), active in South Africa since the early 2000s, plays a crucial role in this effort (Nair et al., 2023). WIETA, described as "a multi-stakeholder organization representing trade unions, civil society groups, wine brands, and producers, is dedicated to fostering fair working conditions in the wine industry and facilitating ethical trade discussions" (WIETA, 2024). Their Ethical Code of Conduct serves as a comprehensive framework for monitoring members and their supply chain. Social audits, a primary monitoring tool, not only assess legal compliance but also ensure alignment with sustainable ethical principles in company management systems. These audits also inspect farm worker housing for safety, health, and sanitation standards while promoting fundamental rights such as dignity, family life, and broader community development (WIETA, 2024).

Ukraine is a country that has faced several challenges over time. According to the Wines of Ukraine organization website (WU, 2024), Ukraine has a rich history of winemaking, but the struggle for the territory of Ukraine has been going on for centuries, impacting the development of winemaking. Moreover, the ongoing war has imposed substantial damage, with occupied wineries, looted establishments, mined vineyards left uncultivated, and a contraction in the local market. A decade before the Russian invasion, Ukrainian wine experienced a renaissance. The country has been rediscovering a wine-drinking culture that had largely disappeared during the Soviet period (Adler, 2023). Factors such as increased domestic consumption, rising costs of imported wines, favorable legislative changes, and improved wine quality, all contributed to this renaissance (Keay, 2023). While the conflict has somewhat impaired this renascence, various wine journals and newspapers highlight the motivation, resilience, and determination of certain winegrowers and winemakers during the full-scale war, showcasing success stories that yielded quite good harvests over these 2 years (Adler, 2023; Keay, 2023; Naylor, 2023; O'Connor, 2023; Rail, 2023). Despite the challenges of the conflict, the wine-growers diligently tend vineyards, produce wines and export their products worldwide, laying the groundwork for a promising future for the nation's wine industry and contributing to the country's restoration. O'Connor (2023), citing owners and commercial directors of wineries, reveals an optimistic vision for the industry in 2024, with plans to boost sales, expand exports, and introduce new products featuring indigenous varieties. Furthermore, the global wine community has rallied in support of Ukrainian winemakers since the outbreak of the war and the international interest in Ukrainian wine is growing. In its article, O'Connor (2023) quotes Tania Olevska, owner of Friends Wine Travel: "Winemakers had no alternative but to continue nurturing vineyards and pursuing their craft. Emotionally, it's crucial to stay engaged during wartime; otherwise, despair takes hold. Thus, despite the conflict, we enjoyed a bountiful harvest last year. This year is looking promising too." This underscores the

significant role that vitiviniculture can play not only in economic revitalization but also in boosting the resilience of individuals in conflict zones.

2.2 Environmental goals

2.2.1 Affordable clean water and sanitation (SDG 6)

The SDG 6, "Clean Water and Sanitation," aims to achieve universal access to safe and affordable drinking water and sanitation for all. This goal involves financing adequate infrastructure, providing sanitation facilities, encouraging hygiene and protecting as well as restoring water-related ecosystems (UN, 2024a; UNDP, 2024).

The overall water footprint of wine production is estimated to be as high as 1,000 L per 1 L of wine (Bolzonella et al., 2019). The wine sector can contribute to achieve the SDG 6 by applying management practices which reduce water pollution and recycling and increase the water-use efficiency of the sector. The majority of the overall water footprint is attributed to vineyard (Vaclav et al., 2022). Primarily, it is crucial to prioritize the preservation of soil water in vineyards and enhance water use efficiency by grapevines, reducing the need for irrigation. When irrigation is necessary, adopting water- efficient techniques becomes mandatory. Despite its widespread use for weed control, tillage often leads to runoff and contamination, especially on sloped lands, thus it is discouraged (Bagagiolo et al., 2018; Marques et al., 2020). Soil management practices such as non-tillage systems, mulching, cover crops, and compost application can limit evaporation, improve water infiltration, decrease erosion and runoff, and reduce the contamination of water bodies with sediment and agrochemicals (Dinis et al., 2024).

Organic mulch, derived from mowing crops or other residues, when applied under the vineyards soil can decrease soil evaporation by 10–30% (Hayes et al., 2021) and offers benefits such as weed control, erosion prevention, and improved soil and biodiversity (Morlat and Chaussod, 2008; Medrano et al., 2015; Buesa et al., 2021; Mairata et al., 2023). Proper management of cover crops enhances soil health, water retention and infiltration, runoff prevention, and biodiversity (Bagagiolo et al., 2018; Abad et al., 2021). Attention to cover crop management is crucial, particularly in water-limited environments, to avoid competition with grapevines for water and nutrients, the choice of cover crops species and the establishment of the period of the year in which the covers are active should be site-specific (Medrano et al., 2015; Marques et al., 2020; Rodrigo-Comino et al., 2020; Abad et al., 2021). Numerous conditioners have been described as efficient in vineyards, such as biochar, organic compost, plant residues, zeolites, clay minerals, etc., improving soil structure and water retention (Morlat and Chaussod, 2008; Marshall et al., 2019; Cataldo et al., 2022b; Garbowski et al., 2023; Mairata et al., 2023).

Grapevines, like all plants, depend on water for essential physiological processes. Water use efficiency (WUE) of crops refers to the amount of biomass or yield produced per unit of water consumed. Practices like deficit irrigation, smart irrigation, the use of drought-resistant rootstocks and adjusted training systems, mulching, and the application of physical barriers such as kaolin application and shading nets to limit sunlight incidence and reduce leaf temperature, are a few examples that enable improved water usage efficiency by the grapevines (Medrano et al., 2015; Van Leeuwen et al., 2019; Dinis et al., 2020, 2024; Buesa et al., 2021; Cataldo et al., 2022a). Additionally, advancements in irrigation technology, such as soil moisture sensors and remote sensing applications, offer invaluable insights into the water requirements of grapevines, enabling growers to optimize irrigation strategies effectively. Enhancing grapevine WUE not only conserves water resources but also enhances the resilience of vineyards to climate change-induced water scarcity while ensuring grape quality and yield consistency, aligning also with the SDG 2.

Even though wineries' water footprint represents only 1% of all processes, often exceeding 1 L water per L wine, most of this water eventually becomes wastewater, carrying high organic loads that can overwhelm municipal treatment plants, leading to operational issues (Vaclav et al., 2022). To align with the SDGs wineries can implement systems to capture and treat wastewater. Various wastewater treatment technologies, such as constructed wetlands, physicochemical, biological, membrane filtration, and advanced oxidation processes, have been evolving, offering a wide range of treatment options with satisfactory efficiencies for winery wastewater treatment (Vaclav et al., 2022; Giacobbo et al., 2023; Melchiors and Freire, 2023). These treatments aim to achieve substantial reductions in organic and inorganic loads, as well as decreases in suspended solids. However, each technology has its specificities regarding efficiency, removal of key pollutants, and associated costs (Melchiors and Freire, 2023). Evaporation, membrane bioreactor, and reverse osmosis are expected to become more popular in the near future (Vaclav et al., 2022). However, for small wineries, certain technologies can incur notably higher costs, encompassing both capital and operating expenditures. Conventional biological processes remain the best options for small capacities due to their cost- effectiveness and satisfactory removal of organic matter (Vaclav et al., 2022; Melchiors and Freire, 2023). In the context of the circular economy, treated wastewater can serve as an important and low-cost resource for irrigation, providing water and nutrients (Vaclav et al., 2022; Giacobbo et al., 2023). However, selecting the appropriate treatment system that ensures compliance with legal requirements for reuse while preventing negative impacts on the ecosystem is crucial (Giacobbo et al., 2023). Lastly, giving more attention to water footprint assessments throughout the wine production chain can help identify areas of high-water usage and prioritize water-saving interventions.

2.2.2 Affordable clean energy (SDG 7)

The SDG 7, "Affordable and Clean Energy," strives to ensure access to affordable and sustainable energy for all across the globe. The goal emphasizes the importance of expanding renewable energy sources, upgrading technology to provide clean and more efficient energy (UN, 2024a; UNDP, 2024). While wine production might not seem directly related to energy, it intersects with various aspects of sustainability that can positively impact SDG 7 and contribute to increasing the global rate of improvement in energy efficiency.

The wine industry is highly energy-intensive, with electricity consumption ranging from 3 to 25 $kWh\,hl^{-1}$ of wine produced, depending on factors such as quality and facility size. Smaller facilities tend to have higher consumption rates. Electricity accounts for 92% of primary energy sources, followed by fossil fuels like gas, diesel, and fuel oil (8%) (UPM, 2013). Despite size

being the main factor affecting energy consumption, significant differences exist among facilities of the same size, indicating considerable potential for energy savings in this industry (UPM, 2013).

It is crucial for the industry to focus not only on reducing energy consumption but also on the origin of that energy. Generating clean energy is of paramount importance. Implementing photovoltaic modules on buildings and over vineyards, deploying wind turbines on open lands, and using biomass to power operations can reduce dependence on fossil fuels (Carroquino et al., 2018; Montalvo et al., 2020; Padilla et al., 2022; De Castro et al., 2024). For example, in a specific case study, a winery's wastewater treatment plant and the irrigation system's pumping station are supplied by a renewable energy system comprising three photovoltaic arrays connected to a microgrid. Additionally, a hydrogen production and refueling station enables diesel savings. In the study, the electricity (72 MWh) and hydrogen (1,214 m^3) produced saved approximately 27 tons of equivalent CO_2 emissions (Carroquino et al., 2018). Another interesting example is the anaerobic digestion of organic residues from the wine industry to produce biogas, which can offset a winery's energy consumption. Montalvo et al. (2020) investigated the use of different organic residues and found that the wine less and the waste-activated sludge had the highest methane yields, while the wine shoots had the lowest. Improving energy efficiency throughout the winemaking process, including grape processing, fermentation, and bottling stages, is advisable.

Implementing energy-efficient practices such as natural ventilation, thermal insulation, and the installation of efficient lamps or electronic ballasts can significantly reduce energy consumption (UPM, 2013; De Castro et al., 2024). Many measures can be taken to improve the energy efficiency of winemaking equipment, process methodologies, and technologies (De Castro et al., 2024). Cooling processes represent the primary energy consumption in wineries, underscoring the critical need to enhance their energy efficiency. Various strategies can be employed to achieve this, including the use of systems for cold storage using ice, use of automation devices with algorithms to control the cooling equipment (UPM, 2013), insulation of storage tank (11–21% of savings) and integration of solar cooling system (up to 41% savings) (Malvoni et al., 2017), or use different yeasts that can perform fermentation at greater temperatures (Giovenzana et al., 2016). Transporting grapes from vineyards to wineries and distributing wine to markets involves significant energy consumption. Optimizing logistics and adopting sustainable transportation practices such as electric vehicles or biodiesel-powered trucks can reduce the carbon footprint of transportation in the wine distribution chain.

With increasing environmental awareness among consumers, sustainable products with smaller carbon footprints are increasingly valued. For instance, research on consumers of California Sauvignon Blanc in the USA revealed a notable willingness to pay more for various sustainability attributes (Tait et al., 2019). Similarly, studies conducted in Italy have shown a preference among customers for locally sourced products (Stanco and Lerro, 2020). By adhering to environmentally friendly practices, including energy management, the wine industry can leverage organic and sustainability certifications to demonstrate its commitment to sustainability. While consumers prioritize attributes such as pest and disease management, water resources, and food safety, there is a need to increase awareness of the importance of energy efficiency for climate neutrality (Tait et al., 2019; Stanco and Lerro, 2020). Finally, additional strategies can be employed, such as energy audit, a powerful tool to identify areas where energy is being used inefficiently; carbon footprint calculations; and staff education on the importance of energy efficiency (De Castro et al., 2024).

2.2.3 Sustainable cities and communities, and responsible resources use (SDGs 11 and 12)

The SDG 11, "Sustainable Cities and Communities," aspires to create inclusive, safe, resilient, and sustainable cities and human settlements. The goal focuses on creating cities and communities that ensure access to basic services for all residents while minimizing environmental impact, then building resilient societies and economies and fostering social cohesion (UN, 2024a; UNDP, 2024). The SDG 12, "Responsible Consumption and Production," is dedicated to ensure sustainable consumption and production of goods and resources, reducing our ecological footprint. The goal emphasizes the need for sustainable practices in the use of resources, reduction of waste, and promotion of eco-friendly production processes, achieving resource efficiency and a circular economy (UN, 2024a; UNDP, 2024).

In the context of the wine industry, both SDGs 11 and 12 are closely interconnected, aligning efforts toward achieving one can significantly contribute to progress in the other. The OIV resolution on sustainable vitiviniculture emphasizes the need for companies to assess the socio-economic ramifications of their operations and actively contribute to the socioeconomic development of their territories (OIV, 2016). Initiatives such as promoting resilient and sustainable communities, adopting circular economy practices, supporting sustainable consumption and production patterns, implementing responsible public procurement policies, and engaging communities in awareness-raising and capacity-building efforts are pivotal to more sustainable and resilient urban environments.

Resilient and sustainable cities addressed in SDG 11 can be positively impacted by the wine industry in several ways. By integrating sustainability principles into their operations, such as efficient resources use, waste management and circular economy, wineries can contribute to urban resilience (as discussed in SDG 6, 7 and 13). Additionally, initiatives like promoting urban agriculture and incorporating vineyards into urban or peri-urban areas can enhance urban biodiversity, mitigate the urban heat island effect, and improve residents' quality of life. A prime example is the design of an airport with a vineyard on its roof in Florence, demonstrating Tuscany's deep connection to viticulture and winemaking (Levine, 2024) notes, "From their window seats, future visitors landing at the Amerigo Vespucci Airport in Florence will catch the view of a 19-acre vineyard gently sloping upward toward the new international terminal."

Furthermore, wineries often serve as major tourist attractions, contributing to economic development in both urban and rural areas. Sustainable wine tourism, deeply rooted in local culture and environment, fosters community participation and endorsement, which are essential for its advancement (Xu et al., 2016; Yu et al., 2018). Wine tourism supports rural development by creating jobs, boosting local product sales, enhancing regional tourism

infrastructure, and stimulating investment across sectors (Kastenholz and Figueiredo, 2014; Pellin and Vieira, 2015). Regions with thriving wine industries, such as Piemonte (Italy), Mendoza (Argentina), La Rioja (Spain), Bordeaux (France), Napa Valley (USA), and notably, Douro valley (Portugal) have witnessed significant economic benefits from wine tourism. For instance, in Vila Nova de Gaia, renowned for its Port Wine Cellars, tourism driven by wineries has consistently increased, and in 2019 welcomed over 1.5 million visitors (Andrade-Suárez and Caamaño-Franco, 2020). However, sustainable wine tourism requires careful coordination among stakeholders, including governmental entities, tourism agencies, winemakers, wine-growers, neighboring businesses, and residents (Skinner, 2000). The success of sustainable wine tourism hinges on recognizing and addressing challenges related to resource utilization (land, water, labor, capital, and infrastructure), specific tourism advancements (visitor amenities, wine-focused centers, museums, themed villages, and excursions), and the unique impacts of wine-related tourism (rural road congestion, growth of amenities and services, and changes in spending behaviors) (Poitras and Donald, 2006).

Moreover, the wine industry can also contribute to creating inclusive, safe and resilient settlements by promoting social cohesion and equity (as discussed in SDGs 4, 5, 10 and 16), by engaging with local communities through outreach programs, educational initiatives, and partnerships with local organizations, and also by supporting community events, and investing in social projects and promoting responsible drinking practices (aligned with SDG 3).

To promote "Responsible Consumption and Production," SDG 12 emphasizes the importance of sustainable practices throughout the production and consumption chain, including water, energy, and climate-related issues (discussed in SDGs 6, 7 and 13). Practices, such as organic or biodynamic farming techniques, which promote biodiversity and maintaining soil health (Döring et al., 2019), are also key to achieving this goal. According to the FAO, "organic agriculture is a comprehensive approach to managing production that fosters and enriches the health of agroecosystems, encompassing biodiversity, biological cycles, and soil biology" (FAO, 1999). In the EU, several regulations control organic farming, including Regulation (EC) No. 834/2007 (Regulation – 834/2007, 2007), Regulation (EC) No. 889/2008 (Regulation – 889/2008, 2008), and Regulation (EU) No. 203/12 (Regulation – 203/12, 2012), which outlines rules on organic winemaking.

Moreover, addressing waste management within the viticulture chain, including grape pomace, wastewater, and packaging materials, is essential. As already addressed for SDGs 6 and 7, implementing recycling programs, composting grape pomace, and treating wastewater can minimize waste and pollution (Contreras et al., 2022; Niculescu and Ionete, 2023). Embracing circular economy principles can create value from by-products and reduce the environmental footprint, for instance, grape pomace can be repurposed as animal feed, fertilizer, or raw material for cosmetics or pharmaceuticals, and vine shoots can be used as organic fertilizer, recycling and reusing nutrients to reduce dependence on scarce natural resources (Dorosh et al., 2021; Contreras et al., 2022). Furthermore, sustainable packaging materials, such as recycled glass bottles or lightweight alternatives, contribute to reducing the environmental impact of wine production and distribution (Lichy et al., 2023; Trinh et al., 2023). Educating consumers about sustainable wine production and responsible consumption, alongside labels or certifications indicating sustainable practices, can drive demand for eco-friendly products and support businesses committed to sustainability (Forbes et al., 2009; Delmas and Gergaud, 2021). Sustainable wine tourism can contribute to responsible consumption and production by promoting awareness of eco-friendly practices among tourists and supporting local economies.

2.2.4 Climate change mitigation and adaptation (SDG 13)

The SDG 13, "Climate Action," seeks urgent action to combat climate change and its impacts. The goal encourages urgent and collaborative action to implement measures for mitigating climate change and adapting to its effects, and to safeguard the ecological equilibrium of the planet, thereby ensuring the well-being of both current and future generations (UN, 2024a; UNDP, 2024).

Climate change presents significant challenges to the wine industry, influencing grape cultivation, wine production, and overall vineyard management. Traditional climate conditions optimal for grape growing are being altered due to shifts in temperature and precipitation patterns associated with climate change. Rising temperatures can cause premature grape ripening, affecting flavor profiles and quality (Fraga et al., 2012). Additionally, warming temperatures advance the timing of bud break, flowering, and harvest, disrupting the natural growth cycle and potentially leading to imbalances in sugar and acidity levels (García De Cortázar-Atauri et al., 2017). The increased frequency of extreme weather events such as heatwaves, droughts, frosts, and storms can damage vineyards and reduce grape yields (Jaworski and Hilszczański, 2013).

To address these challenges, the wine industry can adopt several sustainable practices and strategies, many of which also align with the goals of SDGs 6, 7, and 12, as previously discussed. These strategies aim to enhance grapevine resilience to adverse environmental conditions, thereby maintaining yields and wine quality. Additionally, also focus on implementing practices and technologies that contribute to climate change mitigation by reducing greenhouse gas emissions and promoting a circular economy.

As already addressed in SDG 9, investment in research can play an important role. Preserving native and diverse grapevine varieties plays a crucial role in enhancing climate resilience, supporting the sustainability of agricultural sectors, and enriching the uniqueness of wines typicity and tourism experiences. By maintaining a diverse genetic pool, grapevines can better adapt to changing environmental conditions, pests, and diseases, ensuring the long-term viability of viticulture in different regions. Several research groups are dedicated to studying plant diversity. For instance, the Institute of Grapevine and Wine Sciences (ICVV)[4] in Spain focuses on scientific

4 https://www.icvv.es/

investigations in viticulture and oenology. One of its primary research areas is genetics and genomics, which involves estimating and characterizing the existing genetic diversity of grapevines, including cultivar and clone genetic improvement. Numerous published studies from the ICVV have highlighted the importance of genetic diversity for the resilience and quality of grape production (Maraš et al., 2020; Loureiro et al., 2023; Tello and Ibáñez, 2023). Another noteworthy approach is the identification and preservation of biodiversity hotspots. A study conducted by Fort et al. (2024) on La Gomera Island in the Canary Islands, Spain, provides a compelling example. Due to the phylloxera plague that affected Europe at the end of the 19th century, many *Vitis vinifera* L. varieties were lost. However, La Gomera Island is one of the few places where the phylloxera never arrived, allowing grapevines to evolve and adapt to this unique habitat for over 500 years. The study aimed to assess the intervarietal and intravarietal diversity of the island, revealing that the local vine population is considered the most unique in the Canary Islands. In addition to research efforts, local governmental entities are actively involved in preserving these grapevine varieties and the cultural landscape, as well as in recovering abandoned rural areas and promoting sustainable tourism. In December 2022, the "I Symposium Internacional de Uva Forastera Gomera y Vino de Bancales" was organized to discuss a differentiated and high-value agricultural model of heroic viticulture practiced on the island, focusing on the unique grapevine variety of Uva Forastera Gomera. This event brought together regional, national, and international professionals from the wine sector, highlighting the importance of preserving local biodiversity and promoting sustainable, culturally rich tourism (CILG, 2022; RTVC, 2022). Collaboration between wineries and research institutions is crucial for developing new grape varieties that are resilient to climate change and innovative vineyard management techniques (Santillán et al., 2020). In regions where viticulture becomes unsustainable, relocating vineyards to higher elevations or cooler microclimates can be an effective adaptation strategy (Van Leeuwen and Darriet, 2016). In numerous grapevines regions across the EU, grapevines are traditionally cultivated under rainfed conditions. With changing precipitation patterns and increased water scarcity, efficient irrigation practices are essential for sustaining grapevine health and optimizing grape quality. Drip irrigation systems and soil moisture monitoring technologies help conserve water and reduce energy consumption (Van Leeuwen and Darriet, 2016). Adjusting canopy density and orientation can mitigate heat stress on grapevines, providing shade and reducing sunburn damage (Santos et al., 2020). Effective soil management, such as introducing diverse cover crops and rotating grape varieties, enhances vineyard water retention, promotes soil health, and mitigates soil erosion and promotes carbon sequestration (Dinis et al., 2024). These practices also improve pest and disease resistance and buffer against climate-related risks (Neethling et al., 2016).

2.2.5 Sustainable life bellow water and on land (SDGs 14 and 15)

The SDG 14, "Life Bellow Water," is dedicated to conserving and sustainably using the oceans, seas, and marine resources. The goal aims to sustainably manage and protect marine and coastal ecosystems from pollution, as well as address overfishing, and the impacts of climate change on marine ecosystems (UN, 2024a; UNDP, 2024). The SDG 15, "Life on Land," aims to protect, restore, and promote the sustainable use of terrestrial ecosystems, envisioning a world where terrestrial ecosystems thrive, supporting diverse plant and animal life while ensuring the well-being of both the environment and humanity. The goal emphasizes initiatives to counteract land degradation, promote responsible land management, conserve natural habitats and biodiversity, and combat desertification (UN, 2024a; UNDP, 2024).

The benefits of adopting sustainable management practices in the wine industry extend beyond vineyards and wineries, actively contributing to safeguarding life and biodiversity in surrounding aquatic and terrestrial ecosystems. The approaches to SDGs 14 and 15 clearly illustrate this interconnectedness, with some measures discussed in the contexts of SDGs 2, 6, 7, 12, and 13 also playing a vital role here. Therefore, a less extended discussion is used here, grouping just some of the measures already addressed and highlighting.

In line with SDG 14, the wine industry can contribute through: (1) Sustainable water management, to implementing efficient irrigation techniques and improving grapevines WUE, can significantly reduce water usage and prevent over-extraction of crucial water resources, thus maintaining healthy aquatic ecosystems; (2) Reducing runoff and pollution, by implementing sustainable soil management practices, organic farming methods, efficient waste management systems, and minimizing the use of chemical fertilizers and pesticides can prevent harmful runoff into nearby water bodies. This helps in maintaining the water quality in reducing the risk of contamination and habitat degradation for aquatic species; (3) Protecting rivers, estuaries and coastal areas, by engaging in practices that prevent soil erosion and runoff can safeguard marine environments from sedimentation and pollution, benefiting both coastal wineries and those inland, as rivers carry sediments to estuary zones.

For SDG 15, the wine industry can contribute by: (1) Biodiversity conservation, by managing vineyards to maintain natural habitats, planting cover crops, and creating wildlife corridors. Wine tourism can play a substantial role in this, creating attractive locations for nature tourism and encouraging the preservation of diverse ecosystems, that protects plant and animal species; (2) Sustainable land management practices, such as organic farming, using cover crops, and agroforestry, can improve soil health and prevent land degradation, which is crucial for maintaining fertile land and supporting diverse ecosystems; (3) Reforestation and afforestation, the wineries can engage in reforestation projects or maintain forested areas on their properties. This helps in carbon sequestration, improves soil health, and supports local wildlife and auxiliary organisms.

Educating consumers to choose eco-friendly products and promoting sustainable wine tourism also increases the motivation and income for the industry to invest in sustainable practices. These efforts reduce the risk of habitat degradation and help maintain ecosystem equilibrium, also aiding in the achievement of both SDGs 14 and 15 targets.

2.3 Governance goals

2.3.1 Potential partnerships in whole wine chain to achieve the sustainable development goals (SDG 17)

The SDG 17, "Partnerships for the Goals," underscores the importance of strong global partnerships and cooperation for sustainable development. This goal encourages collaboration among governments, businesses, and communities to support the achievement of all SDGs (UN, 2024a; UNDP, 2024).

Considering the interdependency, multidimensional and complex nature of these issues, a holistic and integrated approach is needed to mitigate trade-offs and promote synergies (Ladha et al., 2020). Multi-stakeholder partnerships are recognized as important vehicles for mobilizing and sharing knowledge, expertise, technologies and financial resources (Horan, 2019; Oliveira-Duarte et al., 2021). Ensuring that diverse stakeholders collaborate effectively toward common objectives is fundamental to solving many sustainability challenges (Blomqvist et al., 2005; Oliveira-Duarte et al., 2021). By actively engaging in partnerships and collaboration, the wine industry can play a significant role in advancing sustainable development and contribute to the achievement of all SDGs.

Governmental action is essential in fostering collaboration, transparency and accountability within the wine industry. By establishing incentives, policies, and regulations that encourage stakeholders to prioritize sustainability, governments can drive the achievement of the SDGs outlined in the Agenda 2030, thus promoting global progress toward a sustainable future (Andonova et al., 2022; Cruz, 2023). Specific measures include the attribution of incentives, such as tax breaks, grants for sustainable infrastructure investments, or certification programs that provide recognition. Moreover, the implementation of policies and regulations is crucial to guarantee widespread adherence to sustainability standards and to impose several limitations (Schnurbein, 2020). Such measures foster a culture of environmental responsibility, stimulate innovation in sustainable practices, and safeguard natural resources and ecosystems (Andonova et al., 2022). This proactive approach not only benefits the environment but also enhances the reputation and competitiveness of the wine sector in an increasingly eco-conscious market.

With consumers increasingly prioritizing sustainability, wine producers are compelled to adopt sustainable practices to differentiate themselves in a competitive market (Ferrer et al., 2022; Dressler, 2023; Martínez-Falcó et al., 2023b). Consequently, various sustainable certification programs have emerged in the sector, encouraging winegrowers to embrace sustainability. However, cooperatives, primarily comprising small winegrowers with limited resources, face challenges in enforcing these regulations and must develop strategies to incentivize members to adopt sustainable practices in line with market demands.

SDG 17 also highlights the importance of collaborative efforts and robust partnerships, to drive innovation and transfer knowledge. Effective cooperation and knowledge exchange among scientific researchers, stakeholders, and policymakers are crucial to ensure that cutting-edge research findings are effectively communicated and applied within the wine sector (Enechi and Pattberg, 2020; Cruz, 2023). This includes educational programs, training workshops, and mentorship opportunities aimed at empowering stakeholders with the skills and resources needed to adopt sustainable practices.

Furthermore, SDG 17 stresses the need for inclusive and equitable trade relationships that benefit all stakeholders, especially small-scale producers and marginalized communities (Enechi and Pattberg, 2020). Establishing partnerships based on fair trade principles can empower local grape growers, promote economic development, and preserve cultural heritage. By fostering transparent and ethical trade practices, stakeholders can ensure that the benefits of the wine industry are shared equitably across the value chain.

The feasibility of the initiatives and actions proposed in this manuscript can vary significantly across different wine regions worldwide, and tailored strategies and policies must consider regional specificities and the unique challenges faced by viticulturists and winemakers in different parts of the world. For instance, wine regions span across both the Northern and Southern Hemispheres are characterized by different levels of economic development, corruption, and integration into larger political or economic consortia like the European Union. These differences can create unique constraints and opportunities that could affect the initiatives' implementation. For example, in regions where winemakers face financial constraints, the adoption of advanced tools such as sensors and remote sensing applications may be limited unless supported by external funding or incentives. Similarly, in areas with high levels of corruption or weak governance, enforcing fair labor practices and legal hiring processes might be challenging without strong regulatory frameworks and oversight. The potential for organic cultivation and reduced reliance on chemical plant protection substances also depends on the availability of financial incentives, technical support, and market demand for sustainably produced wines.

This manuscript aims to serve as a wake-up call to policymakers, emphasizing the urgent and escalating need for intervention in the wine industry. We also hope to stimulate more nuanced and regionally appropriate solutions that can effectively support the achievement of the SDGs within the global wine sector.

3 Conclusions and future perspectives

The wine industry's commitment to sustainability underscores its potential to drive positive change across economic, social, and environmental dimensions, positioning it as a crucial ally in achieving the UN SDGs. Vitiviniculture possesses the potential to be a transformative force in advancing the SDGs. Targeted actions can contribute to achieving each SDG while also addressing multiple goals simultaneously.

The synergistic relationship between SDGs 1 (No Poverty) and 2 (Zero Hunger) underscores the importance of increasing grapevine yields, enhancing market access for producers, and bridging the gap between producers and consumers. Campaigns, policies, and legislations aimed at controlling alcohol abuse and promoting safe road traffic, and advocating the moderate consume

of wine for its human health benefits contribute to SDG 3 (Good Health and Well-being). Initiatives to promote inclusive and equitable quality education drive sustainable development and enhance the well-being of stakeholders, aligning with SDG 4 (Quality Education). Persistent structural disadvantages faced by women in the industry underscore the need for sustained efforts to achieve gender equality in employment, aligning with SDG 5 (Gender Equality). Sustainable water management and pollution reduction directly contribute to achieving SDG 6 (Clean Water and Sanitation). Embracing renewable energy, improving energy efficiency, adopting waste-to-energy solutions and promoting sustainable transportation align with SDG 7 (Affordable and Clean Energy). Prioritizing fair labor practices and ensuring safe working conditions fosters job creation and sustainable economic development, supporting SDG 8 (Decent Work and Economic Growth). Technological advancements, sustainable practices, and collaborative efforts contribute to resilient infrastructure and economic development, aligning with SDG 9 (Industry, Innovation and Infrastructure). Efforts in fostering local employment, empowering communities, and promoting fair trade contribute to SDG 10 (Reduced Inequalities). Integration of resilient and sustainable settlements, promotion of circular economy practices, and responsible consumption and production align with SDGs 11 (Sustainable Cities and Communities) and 12 (Responsible Consumption and Production). Prioritizing carbon footprint reduction, implementing sustainable practices, and adopting adaptation measures contribute to SDG 13 (Climate Action). Adopting agricultural, industrial, and marketing practices to protect, restore, and promote sustainable use of aquatic and terrestrial ecosystems aligns with SDGs 14 (Life Below Water) and 15 (Life on Land). Embracing ethical practices and fostering economic development in vulnerable regions, while promoting the establishment of just and inclusive societies, contribute to SDG 16 (Peace, Justice and Strong Institutions). Building resilient, inclusive, and sustainable partnerships and work on the sustainable winemaking practice accreditation is essential for achieving all SDGs, aligning with SDG 17 (Partnerships for the Goals). In conclusion, the wine industry has a multifaceted role in supporting the SDGs (Figure 1). While the wine sector can relate to all the SDGs in some way, some of these connections may have a less direct impact. Nevertheless, even secondary connections deserve attention, as the wine industry, being part of a global system, impacts a broad range of sustainability aspects.

Ultimately, the critical pillar of economic sustainability can be achieved through the implementation of good practices that lead to increased productivity, enhanced product quality, and reduced production costs. This includes recycling and reusing by-products, investing in marketing and certifications that capture consumer attention and increase sales, motivating laborers to perform their work more accurately and efficiently, the responsible use of government subsidies, and implementing measures that promote fair pricing. Additionally, a cost–benefit analysis of adopting sustainable practices should be considered, as long-term profitability can drive sustainable changes in the industry. By embracing sustainable practices, the wine industry can contribute to economic growth, social well-being, and environmental protection, demonstrating that profitability and sustainability can go hand in hand.

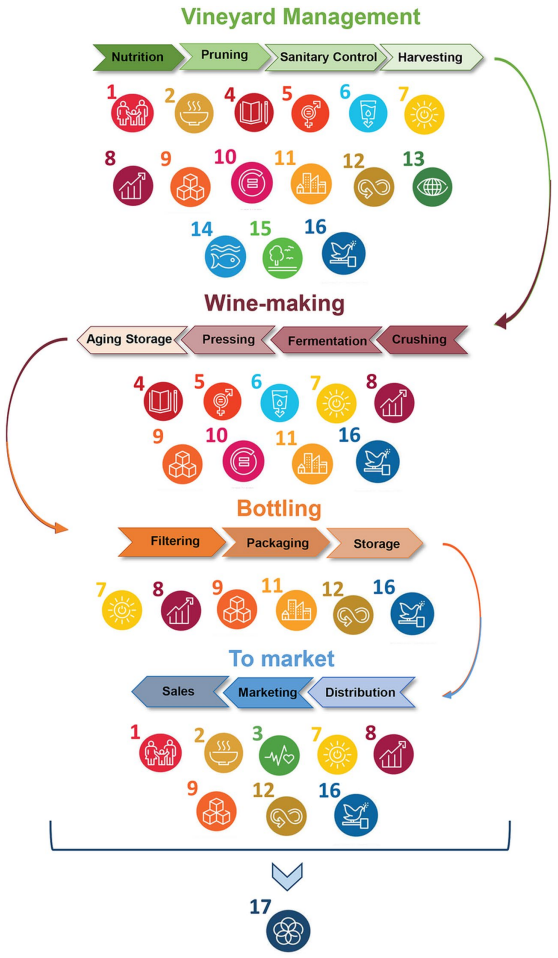

FIGURE 1
Integration of the 17 sustainable development goals (SDGs) across the different steps of the wine chain.

Due to the vast scope of this manuscript, the limitations of this study are mainly related with the weakness of exploring the many examples that could be found worldwide. This manuscript, however, opens the door to a deeper exploration of each SDGs separately, allowing for a more critical analysis of the good and bad practices in this industry. Looking ahead, it is essential for the wine industry to continue its commitment to sustainability and to address the gaps that exist in achieving the SDGs. Key areas for future focus have been identified. By prioritizing these areas and continuing to embrace sustainability, the wine industry can play a vital role in advancing the global agenda for a more equitable, resilient, and sustainable future.

While progress has been made in adopting sustainable practices, there remains room for further research and innovation in developing sustainable viticulture and winemaking practices, e.g., to mitigate environmental impacts, reduce carbon emissions, improve resource use efficiency, and develop eco-friendly packaging solutions. Ethical and equity issues also demand attention. Promoting ethical and fair business practices, fostering community engagement, and supporting social justice and inclusivity initiatives are vital. Addressing gender disparities by empowering women in the sector through policies for equal pay, leadership roles, and career advancement opportunities is equally important. Furthermore, encouraging greater collaboration among

stakeholders, including small vine and wine producers, is crucial for sharing knowledge, resources, and best practices. Partnerships with governments, non-governmental organizations, and other stakeholders can help develop and implement effective sustainability initiatives. Efforts should also be made to increase awareness and education among industry stakeholders, consumers, the broader community, and policymakers about the importance of sustainability in the wine industry and its contribution to the SDGs. The look for more supportive policies and regulations at local, national, and international levels that incentivize and reward sustainable practices is essential. Implementing robust monitoring and reporting mechanisms to track progress toward sustainability goals and identify areas for improvement is imperative.

Finally, the wine industry's strategies for sustainability can serve as a model for other sectors, highlighting the interconnectedness of global efforts to achieve the SDGs.

Author contributions

CB: Investigation, Writing – original draft, Writing – review & editing. SP: Investigation, Writing – original draft. SM: Investigation, Writing – original draft. AM: Writing – original draft. JM-P: Conceptualization, Writing – review & editing. LD: Conceptualization, Investigation, Writing – original draft.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This research was funded by the Foundation for Science and Technology (FCT, Portugal) and FEDER under Program PT2020 for financial support to CITAB (UIDB/04033/2020). https://doi.org/10.54499/UIDB/04033/2020.

Acknowledgments

The authors are grateful for the Mediterranean Area (PRIMA), and the European Union provided in the development of the VineProtect project (PRIMA/0011/2021).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

References

Abad, J., Hermoso De Mendoza, I., Marín, D., Orcaray, L., and Santesteban, L. G. (2021). Cover crops in viticulture. A systematic review (1): implications on soil characteristics and biodiversity in vineyard. *OENO One* 55, 295–312. doi: 10.20870/oeno-one.2021.55.1.3599

Abreu, S., Martins, M. L., and Morais, C. (2024). Wine consumption and health: the dilemma. *Adv. Bot. Res.* (In press). doi: 10.1016/bs.abr.2024.07.003

Adler, N. (2023). Inside Ukraine's wartime wine industry. AlJazeera. Available at: https://www.aljazeera.com/features/2023/3/12/inside-ukraines-wartime-wine-industry (Accessed May 23, 2024).

Ahmadzai, H., Tutundjian, S., Dale, D., Brathwaite, R., Lidderr, P., Selvaraju, R., et al. (2022). Marginal lands: potential for agricultural development, food security and poverty reduction. Rome, Italy: FAO.

Andonova, L. B., Faul, M. V., and Piselli, D. (2022). Partnerships for sustainability in contemporary global governance: pathways to effectiveness. *1st* Edn. London: Routledge.

Andrade-Suárez, M., and Caamaño-Franco, I. (2020). The relationship between industrial heritage, wine tourism, and sustainability: a case of local community perspective. *Sustain. For.* 12:7453. doi: 10.3390/su12187453

ANSA (2019). Doctors say over 1,500 migrant farm workers have died in Italian fields. InfoMigrants. Available at: https://www.infomigrants.net/en/post/15993/doctors-say-over-1500-migrant-farm-workers-have-died-in-italian-fields (Accessed May 23, 2024).

Artero, A., Artero, A., Tarín, J. J., and Cano, A. (2015). The impact of moderate wine consumption on health. *Maturitas* 80, 3–13. doi: 10.1016/j.maturitas.2014.09.007

Atkin, T., Gilinsky, A., and Newton, S. K. (2011). Sustainability in the wine industry: altering the competitive landscape?, in Proceedings of the 6th AWBR international conference, (Bordeaux Management School: Talence, France), 9–10.

AWE. (2024). Inform, inspire, educate. Available at: https://wineeducators.com/ (Accessed August 1, 2024).

Bagagiolo, G., Biddoccu, M., Rabino, D., and Cavallo, E. (2018). Effects of rows arrangement, soil management, and rainfall characteristics on water and soil losses in Italian sloping vineyards. *Environ. Res.* 166, 690–704. doi: 10.1016/j.envres.2018.06.048

Bakari, S. (2017). Why is South Africa still a developing country? Munich Personal RePEc Archive 80763. Available at: https://mpra.ub.uni-muenchen.de/80763/ (Accessed May 23, 2024).

Bandinelli, R., Acuti, D., Fani, V., Bindi, B., and Aiello, G. (2020). Environmental practices in the wine industry: an overview of the Italian market. *Br. Food J.* 122, 1625–1646. doi: 10.1108/BFJ-08-2019-0653

Benedetto, G., and Corinto, G. L. (2015). "The role of women in the sustainability of the wine industry: two case studies in Italy" in The sustainability of agro-food and natural resource systems in the Mediterranean Basin. ed. A. Vastola (Cham: Springer International Publishing), 173–187.

Blomqvist, K., Hurmelinna, P., and Seppänen, R. (2005). Playing the collaboration game right—balancing trust and contracting. *Technovation* 25, 497–504. doi: 10.1016/j.technovation.2004.09.001

Bolzonella, D., Papa, M., Da Ros, C., Anga Muthukumar, L., and Rosso, D. (2019). Winery wastewater treatment: a critical overview of advanced biological processes. *Crit. Rev. Biotechnol.* 39, 489–507. doi: 10.1080/07388551.2019.1573799

Brown. (2021). 16 Programs that's support a more diverse wine, beer, and spirit industry. Available at: https://www.foodandwine.com/fwpro/programs-diversity-wine-beer-spirits-industry (Accessed August 1, 2022).

Buesa, I., Mirás-Avalos, J. M., de Paz, J. M., Visconti, F., Sanz, F., Yeves, A., et al. (2021). Soil management in semi-arid vineyards: combined effects of organic mulching and no-tillage under different water regimes. *Eur. J. Agron.* 123:126198. doi: 10.1016/j.eja.2020.126198

Calicioglu, O., Flammini, A., Bracco, S., Bellù, L., and Sims, R. (2019). The future challenges of food and agriculture: an integrated analysis of trends and solutions. *Sustain. For.* 11:222. doi: 10.3390/su11010222

Carneiro, G. A., Padua, L., Peres, E., Morais, R., Sousa, J. J., and Cunha, A. (2022). Segmentation as a preprocessing tool for automatic grapevine classification., in IGARSS 2022–2022 IEEE international geoscience and remote sensing symposium, (Kuala Lumpur, Malaysia: IEEE), 6053–6056.

Carroquino, J., Roda, V., Mustata, R., Yago, J., Valiño, L., Lozano, A., et al. (2018). Combined production of electricity and hydrogen from solar energy and its use in the wine sector. *Renew. Energy* 122, 251–263. doi: 10.1016/j.renene.2018.01.106

Castaldo, L., Narváez, A., Izzo, L., Graziani, G., Gaspari, A., di Minno, G., et al. (2019). Red wine consumption and cardiovascular health. *Molecules* 24:3626. doi: 10.3390/molecules24193626

Cataldo, E., Fucile, M., and Mattii, G. B. (2022a). Effects of kaolin and shading net on the ecophysiology and berry composition of sauvignon blanc grapevines. *Agriculture* 12:491. doi: 10.3390/agriculture12040491

Cataldo, E., Salvi, L., Sbraci, S., Manzi, D., Masciandaro, G., Masini, C. M., et al (2022b). Zeowine: The synergy of zeolite and compost. Effects on the physiology of the vine and on the quality of the grapes. *BIO Web Conf.* 44. doi: 10.1051/bioconf/20224402002

Charters, S. (2006). Wine and society: the social and cultural context of a drink. Amsterdam; Boston: Elsevier/Butterworth-Heinemann.

CILG. (2022) "I Symposium Internacional de Uva Forastera Gomera y Vino de Bancales", Calbido Insular de La Gomera (CILG).Available at: https://www.lagomera.es/evento/i-symposium-internacional-de-uva-forastera-gomera-y-vino-de-bancales (Accessed August 28, 2024).

CMB. (2023). Mateus – a história de sucesso do rosé português mais vendido no mundo. Available at: https://concoursmondial.com/pt/35601-2/ (Accessed August 1, 2024).

Contreras, M. D. M., Romero-García, J. M., López-Linares, J. C., Romero, I., and Castro, E. (2022). Residues from grapevine and wine production as feedstock for a biorefinery. *Food Bioprod. Process.* 134, 56–79. doi: 10.1016/j.fbp.2022.05.005

Counihan, C. M. (2004). Around the Tuscan table: food, family, and gender in twentieth century Florence. New York: Routledge.

Cruz, S. A. (2023). SDG 17 and global partnership for sustainable development: unraveling the rhetoric of collaboration. *Front. Environ. Sci.* 11:1155828. doi: 10.3389/fenvs.2023.1155828

CSWA. (2020). 2020 California wine community sustainability report. Available at: https://library.sustainablewinegrowing.org/item/244/2020-california-wine-community-sustainability-report (Accessed August 1, 2024).

De Castro, M., Baptista, J., Matos, C., Valente, A., and Briga-Sá, A. (2024). Energy efficiency in winemaking industry: challenges and opportunities. *Sci. Total Environ.* 930:172383. doi: 10.1016/j.scitotenv.2024.172383

De Lorenzis, G., Carbonell-Bejerano, P., Toffolatti, S. L., and Tello, J. (2022). Editorial: advances in grapevine genetic improvement: towards high quality, sustainable grape production. *Front. Plant Sci.* 13:1080733. doi: 10.3389/fpls.2022.1080733

Delmas, M. A., and Gergaud, O. (2021). Sustainable practices and product quality: is there value in eco-label certification? The case of wine. *Ecol. Econ.* 183:106953. doi: 10.1016/j.ecolecon.2021.106953

Dinis, L.-T., Bernardo, S., Matos, C., Malheiro, A., Flores, R., Alves, S., et al. (2020). Overview of kaolin outcomes from vine to wine: Cerceal white variety case study. *Agronomy* 10:1422. doi: 10.3390/agronomy10091422

Dinis, L.-T., Brito, C. Q., Correia, C. M., and Moutinho-Pereira, J. (2024). "Chapter three – canopy and soil management strategies: insights to overcome abiotic stresses in grapevine" in Advances in botanical research. ed. P. Martins-Lopes (London, UK: Academic Press), 71–99.

Dodds, R., Graci, S., Ko, S., and Walker, L. (2013). What drives environmental sustainability in the New Zealand wine industry? An examination of driving factors and practices. *Int. J. Wine Bus. Res.* 25, 164–184. doi: 10.1108/IJWBR-2012-0015

Döring, J., Collins, C., Frisch, M., and Kauer, R. (2019). Organic and biodynamic viticulture affect biodiversity and properties of vine and wine: a systematic quantitative review. *Am. J. Enol. Vitic.* 70, 221–242. doi: 10.5344/ajev.2019.18047

Dorosh, O., Fernandes, V. C., Moreira, M. M., and Delerue-Matos, C. (2021). Occurrence of pesticides and environmental contaminants in vineyards: case study of Portuguese grapevine canes. *Sci. Total Environ.* 791:148395. doi: 10.1016/j.scitotenv.2021.148395

Dressler, M. (2023). Sustainable business model design: a multi-case approach exploring generic strategies and dynamic capabilities on the example of German Wine Estates. *Sustain. For.* 15:3880. doi: 10.3390/su15053880

EC (2020). Farm to fork strategy – For a fair, healthy and environmentally-friendly food system – European Commission (EC). European Union. Available at: https://food.ec.europa.eu/system/files/2020-05/f2f_action-plan_2020_strategy-info_en.pdf (Accessed May 12, 2024).

Elam, A.B., Brush, C.G., Greene, P.G., Baumer, B., Dean, M., and Heavlow, R. and Global Entrepreneurship Research Association. (2019). Women's Entrepreneurship Report 2018/2019. Available at: www.gemconsortium.org/report/gem-20182019-womens-entrepreneurship-report (Accessed April 15, 2024).

Enechi, O., and Pattberg, P. (2020). "Building strong partnership for SDGs: analyzing participation of Nigerian stakeholders" in Transitioning to strong partnerships for the sustainable development goals. ed. G.v. Schnurbein (Basel, Switzerland: MDPI).

FAO (1999). FAO – Committee on Agriculture – Organic Agriculture. Available at: https://www.fao.org/4/X0075E/X0075E.htm (Accessed May 23, 2024).

FAO (2016). Food and agriculture: key to achieving the 2030 agenda for sustainable development. Food and Agriculture Organization (FAO). Available at: https://sustainabledevelopment.un.org/content/documents/2313foodandagriculture.pdf (Accessed April 26, 2024).

Ferreira-Borges, C., Neufeld, M., Breda, J., Lima, J. M., and Léon, E. (2020). Alcohol consumption and sustainable development: Fact sheet on sustainable development goals (SDGs): health targets. Copenhagen, Denmark: World Health Organization.

Ferrer, J. R., García-Cortijo, M. C., Pinilla, V., and Castillo-Valero, J. S. (2022). The business model and sustainability in the Spanish wine sector. *J. Clean. Prod.* 330:129810. doi: 10.1016/j.jclepro.2021.129810

FG (2024). FAIR'N GREEN. Responsibility for people, nature and the environment. Available at: https://www.fairandgreen.com/en/ (Accessed August 28, 2024).

Figueiredo, V., and Franco, M. (2018). Wine cooperatives as a form of social entrepreneurship: empirical evidence about their impact on society. *Land Use Policy* 79, 812–821. doi: 10.1016/j.landusepol.2018.09.022

Foguesatto, C. R., Borges, J. A. R., and Machado, J. A. D. (2020). A review and some reflections on farmers' adoption of sustainable agricultural practices worldwide. *Sci. Total Environ.* 729:138831. doi: 10.1016/j.scitotenv.2020.138831

Fonseca, A., Cruz, J., Fraga, H., Andrade, C., Valente, J., Alves, F., et al. (2024). Vineyard microclimatic zoning as a tool to promote sustainable viticulture under climate change. *Sustain. For.* 16:3477. doi: 10.3390/su16083477

Fonseca, L. M., Domingues, J. P., and Dima, A. M. (2020). Mapping the sustainable development goals relationships. *Sustain. For.* 12:3359. doi: 10.3390/su12083359

Forbes, S. L., Cohen, D. A., Cullen, R., Wratten, S. D., and Fountain, J. (2009). Consumer attitudes regarding environmentally sustainable wine: an exploratory study of the New Zealand marketplace. *J. Clean. Prod.* 17, 1195–1199. doi: 10.1016/j.jclepro.2009.04.008

Fort, F., Lin-Yang, Q., Valls, C., Sancho-Galán, P., Canals, J. M., and Zamora, F. (2024). Analysis of the diversity presented by *Vitis vinifera* L. in the Volcanic Island of La Gomera (canary archipelago, Spain) using simple sequence repeats (SSRs) as molecular markers. *Horticulturae* 10:14. doi: 10.3390/horticulturae10010014

Fraga, H., Malheiro, A. C., Moutinho-Pereira, J., and Santos, J. A. (2012). An overview of climate change impacts on European viticulture. *Food Energy Secur.* 1, 94–110. doi: 10.1002/fes3.14

Fuentes-Fernández, R., Martínez-Falcó, J., Sánchez-García, E., and Marco-Lajara, B. (2022). Does ecological agriculture moderate the relationship between wine tourism and economic performance? A structural equation analysis applied to the Ribera del Duero wine context. *Agriculture* 12:2143. doi: 10.3390/agriculture12122143

Gadoury, D. M., Sapkota, S., Cadle-Davidson, L., Underhill, A., McCann, T., Gold, K. M., et al. (2023). Effects of nighttime applications of germicidal ultraviolet light upon powdery mildew (*Erysiphe necator*), downy mildew (*Plasmopara viticola*), and sour rot of grapevine. *Plant Dis.* 107, 1452–1462. doi: 10.1094/PDIS-04-22-0984-RE

Garbowski, T., Bar-Michalczyk, D., Charazińska, S., Grabowska-Polanowska, B., Kowalczyk, A., and Lochyński, P. (2023). An overview of natural soil amendments in agriculture. *Soil Till Res.* 225:105462. doi: 10.1016/j.still.2022.105462

García De Cortázar-Atauri, I., Duchêne, E., Destrac-Irvine, A., Barbeau, G., De Rességuier, L., Lacombe, T., et al. (2017). Grapevine phenology in France: from past observations to future evolutions in the context of climate change. *OENO One* 51, 115–126. doi: 10.20870/oeno-one.2017.51.2.1622

Garcia, F. A., Marchetta, M. G., Camargo, M., Morel, L., and Forradellas, R. Q. (2012). A framework for measuring logistics performance in the wine industry. *Int. J. Prod. Econ.* 135, 284–298. doi: 10.1016/j.ijpe.2011.08.003

Giacobbo, A., Oliveira, M., Bernardes, A. M., and De Pinho, M. N. (2023). "Winery wastewater treatment for biomolecules recovery and water reuse purposes" in *Advanced technologies in wastewater treatment*. eds. A. Basile, A. Cassano and C. Conidi (Elsevier), 311–354.

Gil, J. D. B., Reidsma, P., Giller, K., Todman, L., Whitmore, A., and van Ittersum, M. (2019). Sustainable development goal 2: improved targets and indicators for agriculture and food security. *Ambio* 48, 685–698. doi: 10.1007/s13280-018-1101-4

Giovenzana, V., Beghi, R., Vagnoli, P., Iacono, F., Guidetti, R., and Nardi, T. (2016). Evaluation of energy saving using a new yeast combined with temperature management in sparkling base wine fermentation. *Am. J. Enol. Vitic.* 67, 308–314. doi: 10.5344/ajev.2016.15115

Gomes, M. J., Sousa, A., Novas, J., and Jordão, R. V. D. (2021). Environmental sustainability in viticulture as a balanced scorecard perspective of the wine industry: evidence for the Portuguese region of Alentejo. *Sustain. For.* 13:10144. doi: 10.3390/su131810144

Gonçalves, C., Honrado, J. P., Cerejeira, J., Sousa, R., Fernandes, P. M., Vaz, A. S., et al. (2022). On the development of a regional climate change adaptation plan: integrating model-assisted projections and stakeholders' perceptions. *Sci. Total Environ.* 805:150320. doi: 10.1016/j.scitotenv.2021.150320

Gore, T., Alestig, M., Banerji, S., and Ceccarelli, G. (2021). The workers behind Sweden's Italian wine: an illustrative human rights impact assessment of Systembolaget's Italian wine supply chains. *Oxfam*. doi: 10.21201/2021.7703

Guidi, C. F., and Berti, F. (2023). Labor exploitation in the Italian agricultural sector: the case of vulnerable migrants in Tuscany. *Front. Sociol.* 8:1234873. doi: 10.3389/fsoc.2023.1234873

Hayes, P., Graça, A., Fuente, M., Bois, B., Andrag, A., Savage, C., et al. (2021). Sustainable use of water in winegrape vineyards. France: OIV – International Organisation of Vine and Wine.

He, S., Sun, C., and Pan, Y. (2008). Red wine polyphenols for cancer prevention. *Int. J. Mol. Sci.* 9, 842–853. doi: 10.3390/ijms9050842

Horan, D. (2019). A new approach to partnerships for SDG transformations. *Sustain. For.* 11:4947. doi: 10.3390/su11184947

IPCC (2023). Climate change 2023: synthesis report. contribution of working groups I, II and III to the sixth assessment report of the intergovernmental panel on climate change. Geneva, Switzerland: IPCC, 1–34.

Jaworski, T., and Hilszczański, J. (2013). The effect of temperature and humidity changes on insects development their impact on forest ecosystems in the expected climate change. *For. Res. Pap.* 74, 345–355. doi: 10.2478/frp-2013-0033

Jindo, K., Goron, T. L., Pizarro-Tobías, P., Sánchez-Monedero, M. Á., Audette, Y., Deolu-Ajayi, A. O., et al. (2022). Application of biostimulant products and biological control agents in sustainable viticulture: a review. *Front. Plant Sci.* 13:932311. doi: 10.3389/fpls.2022.932311

Kasimati, A., Papadopoulos, G., Manstretta, V., Giannakopoulou, M., Adamides, G., Neocleous, D., et al. (2024). Case studies on sustainability-oriented innovations and smart farming technologies in the wine industry: a comparative analysis of pilots in Cyprus and Italy. *Agronomy* 14:736. doi: 10.3390/agronomy14040736

Kastenholz, E., and Figueiredo, E. (2014). Rural tourism experiences. Land, sense and experience-scapes in quest of new tourist spaces and sustainable community development. *PASOS Revista de Turismo y Patrimonio Cultural* 12, 511–514. doi: 10.25145/j.pasos.2014.12.037

Keay, J. (2023). How Ukraine wine is having an unexpected renaissance. The Buyer. Available at: https://www.the-buyer.net/insight/ukraine-wine-surviving-wartime-keay (Accessed May 23, 2024).

Ladha, J. K., Jat, M. L., Stirling, C. M., Chakraborty, D., Pradhan, P., Krupnik, T. J., et al. (2020). "Achieving the sustainable development goals in agriculture: the crucial role of nitrogen in cereal-based systems" in Sparks (ed.) Advances in agronomy (Elsevier), 39–116.

Levine, I. S. (2024). This Italian airport will have a vineyard on its roof. Forbes Available at: https://www.forbes.com/sites/irenelevine/2024/02/07/this-italian-airport-will-have-a-vineyard-on-its-roof/ (Accessed May 23, 2024).

Lichy, J., Kachour, M., and Stokes, P. (2023). Questioning the business model of sustainable wine production: the case of French "Vallée du Rhône" wine growers. *J. Clean. Prod.* 417:137891. doi: 10.1016/j.jclepro.2023.137891

Livat, F., and Jaffré, C. (2021). "Women in wine… occasionally: Gendered roles in the wine industry" in *The Routledge Handbook of Wine and Culture*. eds. S. Chartres, M. Demossier, J. Dutton, G. Harding, J. Smith Maguire, D. Marks, et al (New York, NY: Routledge), 1, 320–330.

Loureiro, M. D., Valle, J. M., Ocete, R., López, M. A., Ocete, C. A., Rodríguez-Miranda, A., et al. (2023). Current situation and characterization of the Eurasian wild grapevine in Asturias region (northwest of the Iberian Peninsula). *Vitis* 62, 27–40. doi: 10.5073/vitis.2023.62.27-40

Maicas, S., and Mateo, J. J. (2020). Sustainability of wine production. *Sustain. For.* 12:559. doi: 10.3390/su12020559

Mainali, B., Luukkanen, J., Silveira, S., and Kaivo-oja, J. (2018). Evaluating synergies and trade-offs among sustainable development goals (SDGs): explorative analyses of development paths in South Asia and sub-Saharan Africa. *Sustain. For.* 10:815. doi: 10.3390/su10030815

Mairata, A., Labarga, D., Puelles, M., Huete, J., Portu, J., Rivacoba, L., et al. (2023). The organic mulches in vineyards exerted an influence on spontaneous weed cover and plant biodiversity. *Eur. J. Agron.* 151:126997. doi: 10.1016/j.eja.2023.126997

Malvoni, M., Congedo, P. M., and Laforgia, D. (2017). Analysis of energy consumption: a case study of an Italian winery. *Energy Procedia* 126, 227–233. doi: 10.1016/j.egypro.2017.08.144

Maraš, V., Tello, J., Gazivoda, A., Mugoša, M., Perišić, M., Raičević, J., et al. (2020). Population genetic analysis in old Montenegrin vineyards reveals ancient ways currently active to generate diversity in *Vitis vinifera*. *Sci. Rep.* 10:15000. doi: 10.1038/s41598-020-71918-7

Marco-Lajara, B., Zaragoza-Sáez, P. C., Martínez-Falcó, J., and Sánchez-García, E. (2022). Does green intellectual capital affect green innovation performance? Evidence from the Spanish wine industry. *Br. Food J.* 125, 1469–1487. doi: 10.1108/BFJ-03-2022-0298

Marques, M., Ruiz-Colmenero, M., Bienes, R., García-Díaz, A., and Sastre, B. (2020). Effects of a permanent soil cover on water dynamics and wine characteristics in a steep vineyard in the Central Spain. *Air Soil Water Res.* 13:117862212094806. doi: 10.1177/1178622120948069

Marques, A., and Teixeira, C. A. (2023). Vine and wine sustainability in a cooperative ecosystem—a review. *Agronomy* 13:2644. doi: 10.3390/agronomy13102644

Marshall, J., Muhlack, R., Morton, B. J., Dunnigan, L., Chittleborough, D., and Kwong, C. W. (2019). Pyrolysis temperature effects on biochar–water interactions and application for improved water holding capacity in vineyard soils. *Soil Syst.* 3:27. doi: 10.3390/soilsystems3020027

Martínez-Falcó, J., Marco-Lajara, B., Zaragoza-Sáez, P., and Ruiz-Fernández, L. (2023a). Impact of green intellectual capital on sustainable development goals: insights from Spain's wine industry. *Wine Bus. J.* 1–17. doi: 10.26813/001c.92435

Martínez-Falcó, J., Martínez-Falcó, J., Marco-Lajara, B., Sánchez-García, E., and Visser, G. (2023b). Aligning the sustainable development goals in the wine industry: a bibliometric analysis. *Sustain. For.* 15:8172. doi: 10.3390/su15108172

Martins, A. A., Costa, M. C., Araújo, A. R., Morgado, A., Pereira, J. M., Fontes, N., et al. (2019). Sustainability evaluation of a Portuguese "terroir" wine. *BIO Web Conf.* 12:03017. doi: 10.1051/bioconf/20191203017

McFarlane, J., Mounter, S., Bligh, G., and Fleming, E. (2013). Economic impacts of viticulture and winemaking on employment and income in the central ranges zone of New South Wales, Australia, in 7th annual meeting of the American Association of Wine Economists, Stellenbosch.

Medrano, H., Tomás, M., Martorell, S., Escalona, J.-M., Pou, A., Fuentes, S., et al. (2015). Improving water use efficiency of vineyards in semi-arid regions a review. *Agron. Sustain. Dev.* 35, 499–517. doi: 10.1007/s13593-014-0280-z

Melchiors, E., and Freire, F. B. (2023). Winery wastewater treatment: a systematic review of traditional and emerging technologies and their efficiencies. *Environ. Process.* 10:43. doi: 10.1007/s40710-023-00657-4

Mennell, S. (1992). Sociology of food – eating, diet and culture. ACADEMIA. Available at: https://www.academia.edu/43277709/Sociology_of_Food_Eating_Diet_and_Culture (Accessed May 23, 2024).

Miller, C. (2016). California sustainable winegrowing Alliance trade survey – summary report. California Sustainable Winegrowing Alliance. Available at: https://library.sustainablewinegrowing.org/amass/doc-get-pub/resource/173/CSWA%20Wine%20Opinions%20Trade%20Survey%20Summary%202016.pdf (Accessed March 11, 2024).

Mira de Orduña, R. (2010). Climate change associated effects on grape and wine quality and production. *Food Res. Int.* 43, 1844–1855. doi: 10.1016/j.foodres.2010.05.001

Mollier, L., Seyler, F., Chotte, J.-L., and Ringler, C. (2017). "SDG 2 end hunger, achieve food security and improved nutrition and promote sustainable agriculture" in A guide to SDG interactions: from science to implementation (Paris, France: International Council for Science (ICSU)).

Montalvo, S., Martinez, J., Castillo, A., Huiliñir, C., Borja, R., García, V., et al. (2020). Sustainable energy for a winery through biogas production and its utilization: a Chilean case study. *Sustain Energy Technol Assess* 37:100640. doi: 10.1016/j.seta.2020.100640

Morlat, R., and Chaussod, R. (2008). Long-term additions of organic amendments in a Loire Valley vineyard. I. Effects on properties of a calcareous Sandy soil. *Am. J. Enol. Vitic.* 59, 353–363. doi: 10.5344/ajev.2008.59.4.353

Mozas-Moral, A., Fernández-Uclés, D., Medina-Viruel, M. J., and Bernal-Jurado, E. (2021). The role of the SDGs as enhancers of the performance of Spanish wine cooperatives. *Technol. Forecast. Soc.* 173:121176. doi: 10.1016/j.techfore.2021.121176

Nair, R. D., Chisoro, S., and Ponte, S. (2023). Sustainability in the south African wine industry: status, opportunities and challenges. Centre for Business and Development Studies. Available at: https://research.cbs.dk/en/publications/sustainability-in-the-south-african-wine-industry-status-opportun (Accessed May 23, 2024).

Naylor, A. (2023). War and wine: the struggles and successes of a Ukrainian industry. Radio Free Europe/Radio Liberty. Available at: https://www.rferl.org/a/ukraine-war-wine-industry-struggles-successes/32725692.html (Accessed May 23, 2024).

Neethling, E., Barbeau, G., Tissot, C., Rouan, M., Le Coq, C., Le Roux, R., et al. (2016). Adapting viticulture to climate change: guidance manual to support winegrowers' decision-making. Adviclim. Available at: https://www.vineas.net/pt/7_102/5fca6669b65ec111d9fd24a8/ADAPTING%20VITICULTURE%20TO%20CLIMATE%20CHANGE%20GUIDANCE%20MANUAL%20TO%20SUPPORT%20WINEGROWERS%E2%80%99%20DECISION-MAKING%20(2016).html (Accessed May 23, 2024).

NG (2024). Napa Green. Available at: https://napagreen.org/ (Accessed August 28, 2024).

Niculescu, V.-C., and Ionete, R.-E. (2023). An overview on management and valorisation of winery wastes. *Appl. Sci.* 13:5063. doi: 10.3390/app13085063

O'Connor, L. (2023). Ukraine wine harvest 2023: sipping resilience. Decanter. Available at: https://www.decanter.com/wine-news/ukraine-wine-harvest-2023-sipping-resilience-512303/ (Accessed May 23, 2024).

OIV (2004). Resolution CST 1/2004-development of sustainable Vitiviniculture. International Organisation of Vine and Wine (OIV). Available at: https://www.oiv.int/public/medias/2074/cst-1-2004-en.pdf (Accessed May 10, 2024).

OIV (2016). OIV general principles of sustainable vitiviniculture-environmental-social-economic and cultural aspects OIVCST518-2016. International Organisation of Vine and Wine (OIV). Available at: https://www.oiv.int/public/medias/5766/oiv-cst-518-2016-en.pdf (Accessed May 1, 2024).

OIV (2021). Focus OIV. The world organic vineyard. Available at: https://www.oiv.int/public/medias/8514/en-focus-the-world-organic-vineyard.pdf (Accessed August 28, 2024).

Oliveira-Duarte, L., Reis, D. A., Fleury, A. L., Vasques, R. A., Fonseca Filho, H., Koria, M., et al. (2021). Innovation ecosystem framework directed to sustainable

development goal #17 partnerships implementation. *Sustain. Dev.* 29, 1018–1036. doi: 10.1002/sd.2191

Ornelas-Higdon, J. (2021). Deeply rooted: immigrants and the hidden histories of California's wine industry. Boom California. Available at: https://boomcalifornia.org/2021/06/03/deeply-rooted-immigrants-and-the-hidden-histories-of-californias-wine-industry/ (Accessed May 23, 2024).

OSB (2024). Oregon state bar. Sustainable future section. Available at: https://sustainablefuture.osbar.org/section-newsletter/20102summer5buckenmeyer/ (Accessed August 28, 2024).

Padilla, J., Toledo, C., and Abad, J. (2022). Enovoltaics: symbiotic integration of photovoltaics in vineyards. *Front. Energy Res.* 10:1007383. doi: 10.3389/fenrg.2022.1007383

Pastor, R. F., Restani, P., Di Lorenzo, C., Orgiu, F., Teissedre, P.-L., Stockley, C., et al. (2017). Resveratrol, human health and winemaking perspectives. *Crit. Rev. Food Sci. Nutr.* 59, 1237–1255. doi: 10.1080/10408398.2017.1400517

Payan, C., Gancel, A.-L., Jourdes, M., Christmann, M., and Teissedre, P.-L. (2023). Wine acidification methods: a review. *OENO One* 57, 113–126. doi: 10.20870/oeno-one.2023.57.3.7476

Pellin, V., and Vieira, A. C. P. (2015). Contributions of geographical indications for territorial strengthening in rural space: a case study in southern Brazil. Revista ESPACIOS 36. Available at: https://www.revistaespacios.com/a15v36n08/15360807.html (Accessed May 23, 2024).

Poitras, L., and Donald, G. (2006). Sustainable wine tourism: the host community perspective. *J. Sustain. Tour.* 14, 425–448. doi: 10.2167/jost587.0

Puga, G., Anderson, K., Jones, G., Tchatoka, F. D., and Umberger, W. (2022). A climatic classification of the world's wine regions. *OENO One.* 56, 165–177. doi: 10.20870/oeno-one.2022.56.2.4627

Rail, E. (2023). More than a year into the Russian invasion, Ukraine's wine industry assesses the damage wine enthusiast magazine. WineEnthusiast. Available at: https://www.wineenthusiast.com/culture/industry-news/ukrainian-wine-industry-war/ (Accessed May 23, 2024).

Regulation – 203/12 (2012). Commission Implementing Regulation (EU) No 203/2012 of 8 March 2012 amending Regulation (EC) No 889/2008 laying down detailed rules for the implementation of Council Regulation (EC) No 834/2007, as regards detailed rules on organic wine. Available at: https://eur-lex.europa.eu/eli/reg_impl/2012/203/oj (Accessed May 23, 2024).

Regulation – 834/2007 (2007). Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91. Available at: https://eur-lex.europa.eu/eli/reg/2007/834/oj (Accessed May 23, 2024).

Regulation – 889/2008 (2008). Commission Regulation (EC) No 889/2008 of 5 September 2008 laying down detailed rules for the implementation of Council Regulation (EC) No 834/2007 on organic production and labelling of organic products with regard to organic production, labelling and control. Available at: https://eur-lex.europa.eu/eli/reg/2008/889/oj (Accessed May 23, 2024).

Rodrigo-Comino, J., Terol, E., Mora, G., Giménez-Morera, A., and Cerdà, A. (2020). *Vicia sativa* Roth. Can reduce soil and water losses in recently planted vineyards (*Vitis vinifera* L.). *Earth Syst. Environ.* 4, 827–842. doi: 10.1007/s41748-020-00191-5

RTVC (2022). "La Gomera acoge el I Symposium Internacional de uva forastera y vino de bancales", Radio Televisión Canaria (RTVC). Available at: https://rtvc.es/primer-symposium-internacional-de-uva-forastera-y-vino-de-bancales/ (Accessed August 28, 2024)

Rusere, F., Mkuhlani, S., Crespo, O., and Dicks, L. V. (2019). Developing pathways to improve smallholder agricultural productivity through ecological intensification technologies in semi-arid Limpopo, South Africa. *Afr. J. Sci. Technol. Innov. Dev.* 11, 543–553. doi: 10.1080/20421338.2018.1550936

Sachs, J. D. (2012). From millennium development goals to sustainable development goals. *Lancet* 379, 2206–2211. doi: 10.1016/S0140-6736(12)60685-0

Salmon, J.-M., Ojeda, H., and Escudier, J.-L. (2018). Disease resistant grapevine varieties and quality: the case of bouquet varieties. *OENO One* 52, 225–230. doi: 10.20870/oeno-one.2018.52.3.2139

Sam, F. E., Ma, T.-Z., Salifu, R., Wang, J., Jiang, Y.-M., Zhang, B., et al. (2021). Techniques for dealcoholization of wines: their impact on wine phenolic composition, volatile composition, and sensory characteristics. *Food Secur.* 10:2498. doi: 10.3390/foods10102498

Santa Bárbara. (2024). Sustainable wine tours. Available at: https://www.sustainablewinetours.com/ (Accessed August 1, 2024).

Santillán, D., Garrote, L., Iglesias, A., and Sotes, V. (2020). Climate change risks and adaptation: new indicators for Mediterranean viticulture. *Mitig. Adapt. Strateg. Glob. Chang.* 25, 881–899. doi: 10.1007/s11027-019-09899-w

Santos, J. A., Fraga, H., Malheiro, A. C., Moutinho-Pereira, J., Dinis, L.-T., Correia, C., et al. (2020). A review of the potential climate change impacts and adaptation options for European viticulture. *Appl. Sci.* 10:3092. doi: 10.3390/app10093092

Schmitt, C., and Thompson-Gorry, K. (2021). Refugees help French wine makers fill labour shortages. Available at: https://reliefweb.int/report/france/refugees-help-french-wine-makers-fill-labour-shortages (Accessed August 1, 2024).

Schnurbein, G. (2020). Transitioning to strong partnerships for the sustainable development goals. Basel, Switzerland: MDPI.

Seiferd, S., and Valente, M. (2018). An offer that you can't refuse? Agrimafias and migrant labor on vineyards in Southern Italy. DIW Berlin, No. 1735. doi: 10.2139/ssrn.3180586

SIP (2024). SIP certified. Sustainability in practice. Available at: https://www.sipcertified.org/ (Accessed August 28, 2024).

Skinner, A. (2000). "Napa Valley, California: a model of wine region development" in Wine tourism around the world: Development, management and markets. eds. C. Hall, B. Sharples, B. Cambourne and N. Macionis (Oxford: Butterworth-Heinemann), 283–296.

Snopek, L., Mlcek, J., Sochorova, L., Baron, M., Hlavacova, I., Jurikova, T., et al. (2018). Contribution of red wine consumption to human health protection. *Molecules* 23:1684. doi: 10.3390/molecules23071684

Stanco, M., and Lerro, M. (2020). Consumers' preferences for and perception of CSR initiatives in the wine sector. *Sustain. For.* 12:5230. doi: 10.3390/su12135230

Symington. (2024). Symington family states. Available at: https://www.symington.com/ (Accessed August 1, 2024)

Systembolaget. (2019). Systembolaget's responsibility report 2018, p. 16. Available at: https://iogt.org/wp-content/uploads/2019/11/systembolagets-2018-responsibility-report.pdf (Accessed August 30, 2024).

Tait, P., Saunders, C., Dalziel, P., Rutherford, P., Driver, T., and Guenther, M. (2019). Estimating wine consumer preferences for sustainability attributes: a discrete choice experiment of Californian sauvignon blanc purchasers. *J. Clean. Prod.* 233, 412–420. doi: 10.1016/j.jclepro.2019.06.076

Taylor, D. C., Dodd, T. H., and Barber, N. (2008). Impact of wine education on developing knowledge and preferences: an exploratory study. *J. Wine Res.* 19, 193–207. doi: 10.1080/09571260902891175

Teixeira, T. H. T. (2022). A indústria do vinho de Portugal e sua contribuição para os objetivos de desenvolvimento sustentável – ODS: o caso do Grupo Sogrape. Instituto Superior de Economia e Gestão. Available at: https://www.repository.utl.pt/handle/10400.5/27381 (Accessed May 23, 2024).

Tello, J., and Ibáñez, J. (2023). Review: status and prospects of association mapping in grapevine. *Plant Sci.* 327:111539. doi: 10.1016/j.plantsci.2022.111539

Tomay, K., and Tuboly, E. (2023). The role of social capital and trust in the success of local wine tourism and rural development. *Sociol. Rural.* 63, 200–222. doi: 10.1111/soru.12396

Torres, M. L. L., Cavero-Redondo, I., Martínez-Vizcaíno, V., Bizzozero-Peroni, B., Pascual-Morena, C., and Álvarez-Bueno, C. (2023). Association between wine consumption and cancer: a systematic review and meta-analysis. *Front. Nutr.* 10:1197745. doi: 10.3389/fnut.2023.1197745

Trinh, B. M., Chang, B. P., and Mekonnen, T. H. (2023). The barrier properties of sustainable multiphase and multicomponent packaging materials: a review. *Prog. Mater. Sci.* 133:101071. doi: 10.1016/j.pmatsci.2023.101071

TV (2024). Fédération Nationale Terra Vitis. A certification for sustainable winegrowing. Available at: https://terravitis.com/en/homepage-federation-nationale-terra-vitis/ (Accessed August 28, 2024).

UN (2024a). THE 17 GOALS | Sustainable development. Available at: https://sdgs.un.org/goals (Accessed May 23, 2024).

UN (2024b). United Nations (UN): climate action. United Nations. Available at: https://www.un.org/en/climatechange (Accessed May 23, 2024).

UNDP (2024). United Nations Development Programme (UNDP): sustainable development goals. UNDP. Available at: https://www.undp.org/sustainable-development-goals (Accessed May 23, 2024).

United Nations. (2019). Gender Inequality Index (GII). Available at: https://hdr.undp.org/data-center/thematic-composite-indices/gender-inequality-index#/indicies/GII (Accessed August 1, 2024).

UPM (2013). TESLA project (Transfering energy save laid on agroindustry) – IEE/12/758/SI2.644752 D 4.1: Current process description wineries. UPM – Technical University of Madrid. Available at: https://teslaproject.chil.me/download-doc/63247 (Accessed March 15, 2024).

Vaclav, M., Michal, T., Marta, M., Vitzslav, M., and David, H. (2022). Winery wastewater treatment technologies: current trends and future perspective. *Chem. Eng. Trans.* 94, 847–852. doi: 10.3303/CET2294141

Van Leeuwen, C., and Darriet, P. (2016). The impact of climate change on viticulture and wine quality. *J. Wine Econ.* 11, 150–167. doi: 10.1017/jwe.2015.21

Van Leeuwen, C., Destrac-Irvine, A., Dubernet, M., Duchêne, E., Gowdy, M., Marguerit, E., et al. (2019). An update on the impact of climate change in viticulture and potential adaptations. *Agronomy* 9:514. doi: 10.3390/agronomy9090514

Velasquez, L. S. (2018). DoingDoing it with "Ganas"Mexicans and Mexican Americans shaping the California wine industry it with "Ganas.". *Southern California Quart.* 100, 216–243. doi: 10.1525/scq.2018.100.2.216

Vink, N., Deloire, A., Bonnardot, V., and Ewert, J. (2010). Terroir, climate change, and the future of South Africa's wine industry. In Pre-AARES conference workshop on the World's wine markets by 2030: Terroir, climate change, R&D and globalization, Adelaide, South Australia.

Vink, N., Deloire, A., Bonnardot, V., and Ewert, J. (2012). Climate change and the future of South Africa's wine industry. *Int. J. Clim. Change Strateg. Manag.* 4, 420–441. doi: 10.1108/17568691211277746

VIVA (2024). Sustainability in the Italian wine sector. Available at: https://viticolturasostenibile.org/en/ (Accessed August 28, 2024).

WA (2024). Wines of Alentejo. Available at: https://sustentabilidade.vinhosdoalentejo.pt (Accessed May 23, 2024).

Weiskirchen, S., and Weiskirchen, R. (2016). Resveratrol: how much wine do you have to drink to stay healthy? *Adv. Nutr.* 7, 706–718. doi: 10.3945/an.115.011627

WFA (2009). Australian wine industry stewardship - 2009 NATIONAL REPORT. Winemakers Federation of Australia (WFA). Available at: https://agw.org.au/assets/environment-biosecurity/2009-AWIS-National-Report.pdf (Accessed March, 12, 2024).

WIETA (2024). WIETA: Wine & Agricultural Ethical Trade Association. WIETA: Wine & Agricultural Ethical Trade Association. Available at: https://wieta.org.za/who-are-we/ (Accessed May 23, 2024).

WineInModeration (2024). What is wine in moderation? Available at: http://www.wineinmoderation.eu/pt/ (Accessed May 23, 2024).

WU (2024). Ukrainian wineries and wines – Wines of Ukraine (WU). Available at: https://ukr.wine/ (Accessed May 23, 2024).

Xu, S., Barbieri, C., Anderson, D., Leung, Y.-F., and Rozier-Rich, S. (2016). Residents' perceptions of wine tourism development. *Tour. Manag.* 55, 276–286. doi: 10.1016/j.tourman.2016.02.016

Yu, C.-P., Cole, S. T., and Chancellor, C. (2018). Resident support for tourism development in rural Midwestern (USA) communities: perceived tourism impacts and community quality of life perspective. *Sustain. For.* 10:802. doi: 10.3390/su10030802