Climate change mitigation in the wine sector: sustainable practices in vineyard and winery

Deliverable D5.1

Study on the sustainability status of the Spanish wine sector

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Executive summary

The Spanish wine sector is the world leader in vineyard area and among the foremost wine exporters. However, it faces mounting challenges due to climate change, including rising temperatures, droughts, and extreme weather events. These require the full integration of sustainability and resilience

Although environmental awareness and commitment are high, and there is a clear orientation towards reducing greenhouse gas emissions, the uptake of mitigation and adaptation strategies remains uneven across wineries.

The most established practices include energy efficiency, selective waste management, local sourcing, and the adoption of renewable energies. In contrast, more advanced solutions such as biochar application, integrated water–energy circularity, and fleet electrification exhibit low adoption—primarily due to high costs, technological barriers, and a lack of incentives, especially within SMEs. The principal benefits identified by wineries comprise enhanced reputation, access to new markets, regulatory compliance, and risk reduction; additionally, the uptake of environmental certification—particularly SWfCP and EU organic—is gaining momentum across the sector.

This deliverable includes two pilot cases under the Ecocanvas methodology—biochar-enriched compost and the water–energy nexus—tested at Bosque de Matasnos winery. These complementary experiences provide evidence of the feasibility and replicability of circular economy models in the Spanish wine sector

List of abbreviations

BMA –Bosque de Matasnos
CAP – Common Agricultural Policy
CO_2 – Carbon Dioxide
COP (Coefficient of Performance)
DO – Protected Designation of Origin, PDO
DOCa – Qualified Designation of Origin
EER – Energy Efficiency Ratio
ESG – Environmental, Social and Governance
EU – European Union
FEV – Spanish Wine Federation
GVA – Gross Value Added
HVAC – Heating, Ventilation and Air Conditioning
IOF – Investor-Owned Firm
ISO – International Organization for Standardization
KPI – Key Performance Indicator
kW – Kilowatt
LCA – Life Cycle Analysis
MAPA – Spanish Ministry of Agriculture, Fisheries and Food
OIV – International Organisation of Vine and Wine
OIVE – Spanish Wine Interprofessional Organisation
PV – Photovoltaic
QR – Quick Response (QR code)
ROA – Return on Assets
SABI – Iberian Balance Sheet Analysis System
SD – Standard deviation
SME– Small and Medium-sized Enterprise
SWfCP – Sustainable Wineries for Climate Protection

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1 INTRODUCTION

The Spanish wine sector is facing an increasingly challenging climate scenario. Rising average temperatures, more frequent heat waves, and intensified droughts and extreme events are directly affecting vineyards, shaping water availability, harvest calendars, and production quality. These changes demand a rethinking of both vineyard management strategies and winery business models, placing sustainability and resilience at the core of the sector's future.
At the same time, the European and national regulatory framework reinforces this transition. Initiatives such as the European Green Deal, the new Common Agricultural Policy, the Spanish Climate Change and Energy Transition Law, and national adaptation plans set ambitious goals for emission reductions, resource efficiency, and the promotion of the circular economy. Moreover, the growing importance of sustainability reporting and environmental regulations imposes new requirements on companies while also creating opportunities for financing, differentiation, and competitiveness in international markets.

Against this backdrop, a dedicated study of the Spanish wine sector is particularly relevant. It is a sector that is not only highly exposed to the impacts of climate change but also strategically significant due to its economic and social weight. Spain has the largest vineyard area in the world and ranks among the leading wine producers and exporters, making a substantial contribution to employment, exports, and the agri-food GDP. Furthermore, the sector plays a key role in territorial cohesion, acting as a driver of development in many rural and inland areas. In addition to its economic dimension, wine is deeply embedded in Spanish culture and identity, constituting a strategic asset for tourism, gastronomy, and heritage. These economic, social, and cultural dimensions justify the need to assess the sector's sustainability and resilience, as its adaptive capacity will determine not only future competitiveness but also the preservation of a legacy of great value for Spanish society as a whole.

Despite this importance, a significant knowledge gap remains regarding the actual level of sustainability in Spanish wineries. While numerous mitigation and adaptation measures applicable to viticulture have been identified—from efficient water and energy management to the valorisation of by-products and process digitalization—it is unclear to what extent they are being adopted, what factors influence decision-making, and which barriers limit their implementation. Likewise, little is known about the sector's willingness to embrace circular economy innovations or replicate demonstrative solutions, such as those developed under the LIFE CLIMAWIN project. This lack of systematic evidence hinders the design of effective

support policies and the direction of investments towards those measures with the greatest environmental, economic, and social impact.

This report seeks to bridge this knowledge gap through an in-depth assessment of sustainability in Spanish wineries, with particular attention to the adoption of climate change mitigation and adaptation measures. The analysis examines both the practices currently in place and the underlying barriers and drivers influencing decision-making. In doing so, the study delivers a comprehensive diagnosis of the sector's sustainability performance and offers evidence-based insights to guide policy design, support business strategies, and inform future research, prioritizing actions with the highest potential for environmental, economic, and social impact.
The methodology was structured in several phases. Initial meetings with project partners and sectoral experts were conducted to identify the key issues to be included in the questionnaire. A pre-test was then carried out to refine the design before preparing the final version. The resulting questionnaire not only assessed the environmental commitment of wineries but also incorporated the catalog of measures defined in project deliverable D5.2. Based on this framework, data were collected on the level of implementation of these measures, the barriers to their adoption, the benefits perceived, the motivations for their uptake, and the main sources of information consulted by wineries. In addition, the report applies the Ecocanvas methodology to two circular economy pilot cases—biochar-enriched compost and the water–energy nexus—developed under LIFE CLIMAWIN.

These cases were selected due to the strategic importance of advancing from a linear to a circular economy, where resources are optimized, and waste is transformed into valuable inputs. Analysing these measures through a systematic framework such as Ecocanvas allows for the assessment of their technical and economic viability as well as their replicability potential across other wineries and contexts within the sector.

The document is structured into several sections. It begins with a review of the sustainability context in the Spanish wine sector and its economic and innovation dynamics. This is followed by an analysis of the main mitigation and adaptation measures, complemented by the results of the survey conducted with wineries. Based on this evidence, a prioritization of measures according to their level of adoption is presented as a practical tool for the sector. Subsequently, the results of applying the Ecocanvas methodology to the demonstrative measures implemented at the Bosque de Matasnos winery are discussed. Finally, the report concludes with the main findings and recommendations derived from the study.

2 SUSTAINABILITY IN THE SPANISH WINE SECTOR

Sustainability in the Spanish wine sector is defined as the balanced integration of economic, environmental, and social criteria throughout wine production and marketing, aimed at ensuring the sector's long-term viability and positive environmental contribution (OIV, 2020). The growing emphasis on sustainability is largely a response to escalating environmental, social, and governance requirements, leading to a proliferation of recent studies focusing on the sector's key drivers and the diversity of business and management models.

From a technical and productive perspective, García Castellanos et al. (2022) demonstrate, through lifecycle assessment, that irrigated vineyard systems, while more productive, are associated with higher economic and environmental costs. The gap between conventional and organic management is narrower than expected, suggesting that system structure itself exerts a stronger influence on productive sustainability than choice of agronomic practices.
Environmentally, Maicas and Mateo (2020) highlight the challenge posed by the inadequate management of waste arising from the winemaking process, including pomace, stems, lees, and wastewater. The environmental impact of these by-products, which varies with technical choices, can be substantial unless valorisation or recycling strategies are implemented. Technological innovation thus emerges as a fundamental lever to transform waste into valuable resources, reducing the sector's ecological footprint and advancing a more circular production model.

From a business perspective, García-Cortijo et al. (2023) find that attributes such as staff training, a focus on Horeca channels, and export orientation enhance the perceived value of sustainability, positioning it as a strategic advantage. Even so, economic results are mixed: Muñoz et al. (2021) observe that a stronger environmental commitment does not necessarily imply higher profitability, as the most responsible wineries often exhibit lower return on assets (ROA). By contrast, Ferrer et al. (2023b) contend that, when coupled with robust management and financial resources, a sustainability orientation can significantly drive business growth. These apparently contradictory findings highlight that sustainability does not automatically translate into short-term profitability. Rather, the financial outcomes depend on the type of business model, access to resources, and time horizon considered. In the long run, well-managed sustainability strategies can strengthen competitiveness, even if short-term returns are initially modest.

Further, Ferrer et al. (2023a) identify two business archetypes: one high in sustainability—marked by vertical integration, bottled production, premium positioning, and strong presence in modern channels—and a contrasting low-sustainability model focused on bulk wine sales and minimal knowledge of the end market. These findings suggest that sustainability is as much determined by structural strategic decisions as by environmental or social responsibility.

Comparative research by García-Cortijo et al. (2023) between Spanish and Portuguese wineries confirms that companies with a pronounced growth orientation, strategic vision, and active stakeholder engagement are more likely to adopt sustainable policies. Contextual determinants, however, mean there is no single applicable model.

Finally, Ferrer et al. (2024) highlight that organisational form influences commitment to sustainability: cooperatives, often limited by their structure and resource allocation, tend to lag behind private firms (IOFs) in terms of sustainability orientation. This nuance challenges the common assumption that collective organisation inherently favours sustainable leadership.

Sustainability in the Spanish wine sector results from a dynamic interplay of organisational capabilities, business models, and context, rather than technical or regulatory measures alone. Successfully incorporating sustainability as a coherent strategy can, under the right circumstances, enhance sector competitiveness. To fully understand these dynamics, they must be placed within the evolving regulatory framework of the EU wine sector

2.1 Regulatory and Policy Context in the EU

The European Union's regulatory framework for the wine sector has evolved significantly in recent years, prioritising sustainability, climate adaptation, and innovation in close alignment with the European Green Deal and the reformed CAP 2023–2027 (European Commission, 2025a).

A central element of this evolution is the proposed 2025 EU Wine Reform, currently under negotiation within European institutions. The reform aims to provide greater flexibility to Member States in areas such as vineyard management and the extension of replanting authorisations, while also introducing new mechanisms to address structural overproduction in certain regions. At the same time, the proposal strengthens the link between funding and sustainability, requiring that at least 5% of wine-sector expenditure in national CAP programmes be earmarked for climate and environmental objectives (European Commission,

2025b; European Parliament, 2025). This reform remains at the proposal stage, pending final approval in the legislative process.

The package also promotes diversification and innovation. It encourages the development of alcohol-free wines, adaptive marketing strategies, and the use of digital labelling solutions such as QR codes to respond to evolving consumer preferences. In parallel, support measures increasingly reward wineries that demonstrate environmental responsibility, reduce their carbon footprint, and improve resource efficiency (European Commission, 2025a).

Looking ahead, the Commission emphasises the need to harmonise sustainability criteria, foster knowledge exchange among Member States, and strengthen monitoring and evaluation of sectoral progress. This dual approach seeks to ensure that the transition to a climate-resilient and competitive European wine sector is both regulatory and participatory, combining flexibility with forward-looking governance (European Commission, 2025b; European Parliament, 2025).

Achieving sustainability in the wine sector will ultimately depend on its production systems, organisational models, and territorial structure. A detailed understanding of the sector's economic reality, social significance, and institutional framework is therefore essential to assess the real opportunities and challenges of this transition. The next section provides an overview of the economic structure and dynamics of wine in Spain, as a basis for evaluating the scope of the proposed strategies and policies.

3 ECONOMIC STRUCTURE AND CHARACTERISTICS OF THE WINE SECTOR IN SPAIN

The Spanish wine sector stands as one of the country's most robust and strategic economic pillars, exerting considerable influence both nationally and internationally. Beyond its commercial relevance, Spanish viticulture encompasses a complex value chain—from primary production to export marketing—that plays a vital role in driving rural development, safeguarding employment, and preserving traditional cultural and environmental heritage. This section provides an overview of the economic structure of the sector, summarises its main indicators, and analyses the factors defining Spain's competitive positioning within the European and global context. In doing so, it lays the groundwork for understanding the challenges and opportunities facing the industry during its ongoing transition towards more sustainable and resilient models

3.1 European context: Economic overview and positioning of Spain

Spain occupies a central position in the European and global wine sector, boasting the world's largest vineyard area—approximately 924,000 hectares as of 2024—according to the International Organisation of Vine and Wine. With a wine production of around 31 million hectolitres, Spain consistently ranks among the top three producers globally, only behind Italy and France. Its leadership is further confirmed by being the top exporter of wine by volume and among the top three by value, generating close to €3 billion in export revenues annually, and distributing wine to more than 100 countries (OIV, 2024)

This competitive standing results from the sector's vast diversity and export orientation, as well as Spain's capacity to balance tradition with innovation. However, as highlighted by the European Commission, the Spanish wine sector also faces common European challenges such as price volatility, shifting international demand, and evolving environmental requirements. Spain's continued prominence will depend on its ability to add value, adapt to climate commitments, and strengthen ties across the EU value chain (European Commission, 2024).

Spain's role as one of Europe's largest vineyard holders and wine exporters is not only reflected in comparative statistics; it also translates into significant economic and territorial weight within the country. The following section therefore analyses key national indicators—vineyard area, number of wineries, employment, and turnover—to show how Spain's European leadership materialises in its domestic economy and regional development.

3.2 Economic and Territorial Importance of the Wine Sector

The Spanish wine sector is a cornerstone of the national agri-food system, standing out not only for its economic relevance but also for its contribution to rural sustainability, employment, and local identity. In 2024, Spain had approximately 924,000 hectares of vineyards, more than 532,000 registered viticultural holdings, and nearly 3,925 wine-producing wineries. The number of exporting wineries exceeded 3,995, reflecting a clear international orientation (OIVE, 2025).

As Table 1 summarizes, the sector's economic impact is substantial: annual turnover surpassed €8 billion in 2023, wine exports exceeded €3.5 billion in 2024, and the industry generated about 386,000 jobs, mostly in rural areas. The overall wine value chain contributed €22.35 billion in

Gross Value Added (GVA), representing 1.6% of Spain's GDP, with fiscal contributions of over €4.26 billion annually.

This economic weight is reinforced by viticulture's role in sustaining rural populations and local identity, as business structures ranging from small family farms to large wineries spread activity and resilience throughout the territory

Table 1. Main structural and economic indicators of the spanish wine sector.

Indicator	Value
Productive indicators	
Vineyard area	924,000 ha
Wine-producing wineries	3,925
Exporting wineries	3,995*
Viticultural holdings	>532,000
Economic indicators	
Exports	>€3.5 billion
Sector turnover	>€8 billion (annual)*
Jobs generated	~386,000 jobs
Contribution to GDP	1.6% (€22.35 billion GVA) *
Fiscal contribution	>€4.26 billion*

Source: Data refers to 2023/2024 depending on availability Spanish Wine Interprofessional Organisation,2025
*Latest available data (2023)

The Spanish model of viticulture, therefore, is not only an economic engine but also a driver of territorial balance, innovation, and socio-cultural continuity in rural Spain. The capacity of the wine sector to sustain local economies, generate employment, and anchor rural populations continues to be a defining factor in regional and national development policies.

The data in Table 2 reveal significant shifts in Spain's wine sector during the 2024–2025 campaign, highlighting both productive dynamism and changing market conditions. The increase in total output—driven especially by the marked rise in white wine production—may reflect improved climatic conditions, an evolving varietal mix, or heightened external demand, while the slight reduction in red and rosé wine volumes suggests either temporary adjustment or market consolidation.
The reduction in final stocks, particularly relative to the five-year average, underscores a more efficient synchronisation of supply with market demand and potentially more agile inventory

management practices. Stagnation in domestic consumption continues to pose a structural challenge for the sector, necessitating a strategic export orientation. However, the decline in export volumes, set against stable export values, points towards resilience in international pricing or a progressive focus on higher-value market segments.

Furthermore, the substantial growth in wine imports evidences increasing integration with European markets and may indicate efforts to satisfy specific domestic or industrial requirements through blending or diversification of product offerings. Finally, shifts in the allocation of wine to distillation and vinegar production demonstrate ongoing changes in by-product valorisation and market strategies within the sector.

Domestic per capita wine consumption is projected to continue its declining trend, potentially dropping to around 6.2 litters per person annually by 2030, mainly due to demographic changes and low penetration among younger generations. However, the value of the domestic wine market is expected to grow, driven by inflation and an increasing focus on mid- and high-range wines. This premiumization is complemented by strong export dynamics, with Spain expected to surpass €3.5 billion in annual wine export revenues by the end of the decade, particularly through value-added products (Vinetur, 2025).

Table 2 Production and trade indicators of the Spanish wine sector, 2024-2025 campaign.

Indicator	Value	Variation compared to previous campaign (%)
Wine production	31.1 million hl	+9.6%
Total production (wine + must)	36.8 million hl	+15%
White wine	17.9 million hl	+20.4%
Red and rosé wine	12.6 million hl	−1.9%
Final stocks (wine + must)	43.3 million hl	−10% (vs average of last 5 campaigns)
Wine stocks	39.2 million hl	−2.3%
Must stocks	4.1 million hl	+28.4%
Annual national consumption	9.74 million hl	+0.1%
Wine exports	10.82 million hl / €1,692.9 M	−8.2% vol / +0.1% value
Wine imports	548,000 hl / €165 M	+72.5% vol / +7.2% value
Wine for distillation and vinegar	1.02 million hl	−7% total (−12.9% alcohol / +20% vinegar)

Source: Data from Ministry of Agriculture, Fisheries and Food, 2025.

Looking ahead, market analyses project that the total vineyard area in Spain will gradually decrease to around 900,000 hectares by 2030, primarily due to structural consolidation and the abandonment of less profitable vineyards. At the same time, the number of wineries is expected to decline slightly, stabilizing near 3,800, as businesses seek greater efficiency, investment capacity, and competitiveness. Despite the modest reduction in volume, production value and average wine prices are forecast to rise, supported by a clear strategic shift towards higher-quality, bottled, organic, and sparkling wines (Vinetur, 2025).

These structural transformations underscore the sector's ongoing adaptation and set the stage for a transition towards premiumization, sustainability and a more consolidated business landscape by 2030.

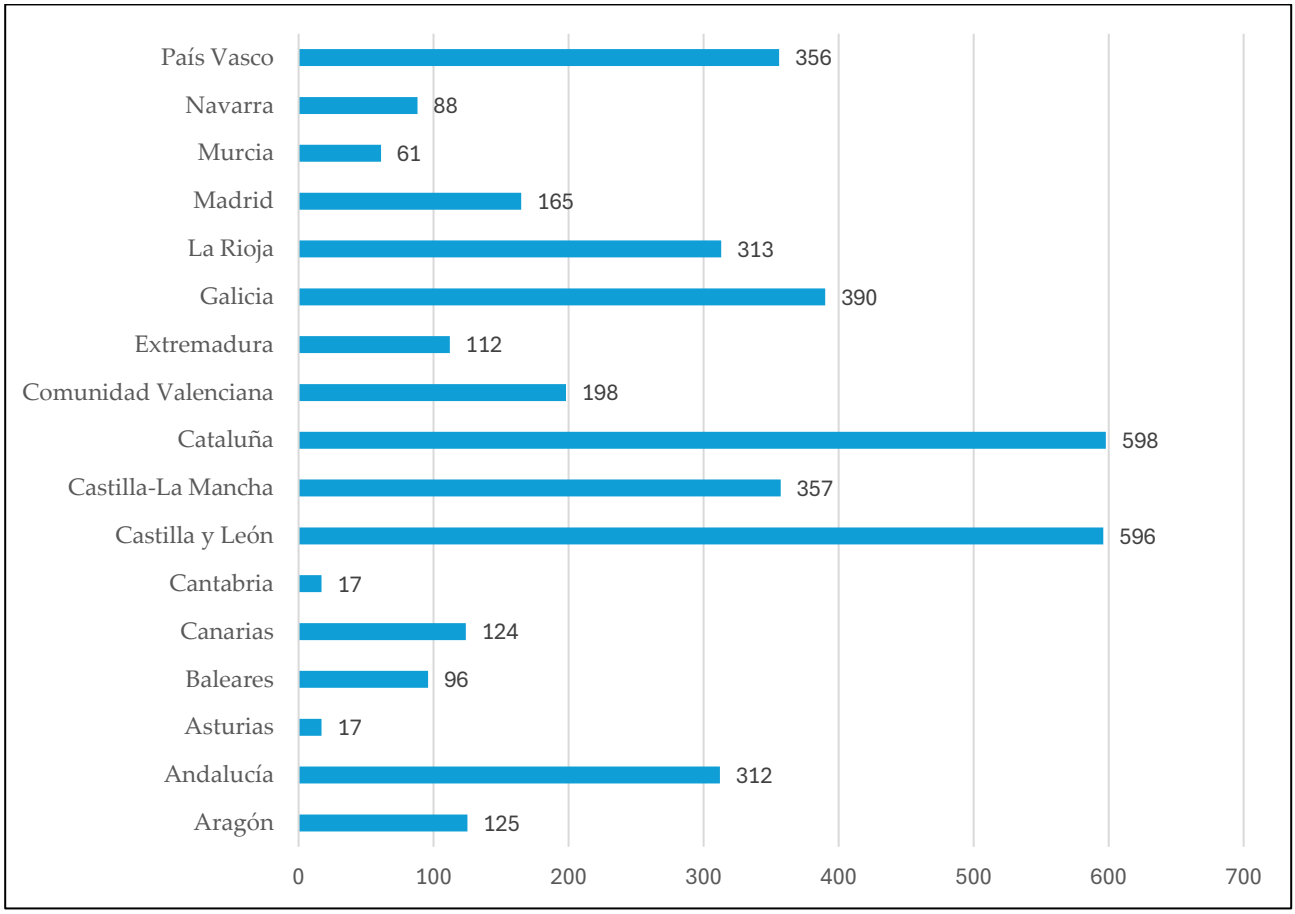
While these national indicators illustrate the overall magnitude and territorial distribution of Spain's wine sector, they do not explain how wineries are actually organised on the ground. Understanding the sector's internal composition—its regional concentration, the prevalence of small family farms, cooperatives, and investor-owned firms—is crucial to grasp the dynamics behind production, innovation, and competitiveness. The following section therefore examines the structure and organisational forms of Spanish wineries.

3.3 Winery Structure and Dynamics

The Spanish wine sector is characterised by a highly heterogeneous and territorially dispersed winery landscape, which is crucial for understanding its adaptability, market orientation, and overall contribution to rural economies. Beyond the sheer number of wineries, structural dimensions such as legal form, regional distribution, and size diversity play a central role in shaping the sector's dynamics.

Figure 1 now presents the distribution of wineries by Autonomous Community (CCAA) in a horizontal bar format, providing a clear visual comparison across regions. The data confirm pronounced concentrations in communities such as Cataluña (598), Castilla y León (596), Galicia (390), La Rioja (313), and Castilla-La Mancha (357). Meanwhile, regions like Cantabria (17), Asturias (17), Murcia (61), and Navarra (88) reflect a much smaller presence. This spatial configuration not only shapes economic output but is also fundamental for maintaining regional wine-making traditions and promoting unique local specialisations.

Figure 1. Number of wineries by Autonomous Community (CCAA). 2024

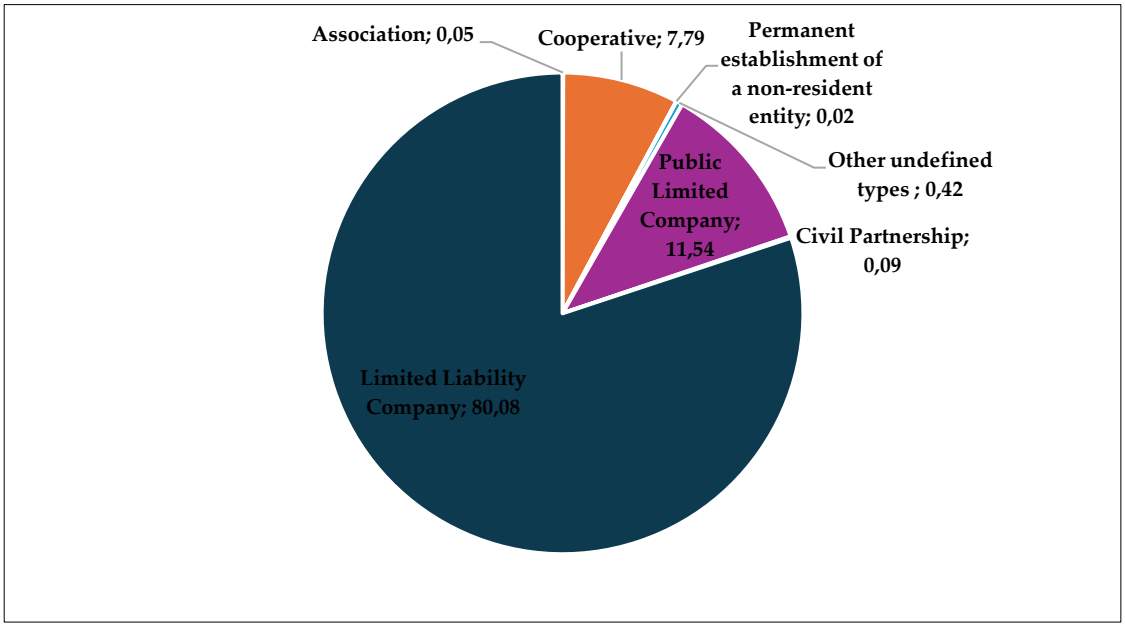


Source: Data from INE,2024

The legal structure of Spanish wineries plays a crucial role in shaping organizational behaviour and strategic orientation. As illustrated in Figure 2, the vast majority of wineries are structured as limited liability companies (80.08%), highlighting a clear preference for this legal form throughout the sector. The next most common forms are public limited companies (11.54%) and cooperatives (7.79%). The significant presence of cooperatives is particularly pronounced in certain regions, reflecting longstanding traditions of collective production and resource sharing. In contrast, private company models—both limited liability and public limited—tend to dominate in export-oriented and vertically integrated markets, where flexibility and individual management are prioritized. Less common legal forms, such as associations (0.05%), civil partnerships (0.09%), permanent establishments of non-resident entities (0.02%), and agricultural transformation companies (0.42%), account for only a minimal share of the total.

This structural landscape underscores the importance of legal form as both a reflection of historical practice and a driver of business strategy within the Spanish wine sector

Figure 2. Legal form of Spanish wineries (%)



Source: Data from SABI

Most Spanish vineyards are characterized by their small size: approximately 69.5% of vineyard holdings in Spain are no larger than 0.5 hectares, highlighting the country's highly fragmented structure, especially in regions like Galicia and Castilla y León where these small holdings represent 97% and 88% of vineyards, respectively. In contrast, only about 4% of Spanish vineyard operations cover more than 10 hectares, with larger estates being more common in regions such as the Basque Country, where over 30% of holdings exceed 10 hectares, and to a lesser extent in Catalonia and Extremadura, where around 18% are in this category (OIV,2024).

This pattern of small-scale farming (minifundismo) means that over 532,000 registered grape growers manage mostly small plots across the country. As a result, Spain's wine sector is notable for its wide geographic dispersion and predominance of small family-owned vineyards, with only a minority of larger-scale operations found in certain regions

The Spanish wine sector is therefore defined by a highly fragmented and regionally dispersed structure, with a predominance of small family holdings and cooperatives alongside a minority of larger investor-owned firms. These organisational and territorial features shape the sector's ability to invest, collaborate and adopt new practices, directly conditioning the pace at which

innovation and digitalisation can spread. The following section examines how these dynamics are materialising through digital strategies, new business models, sustainability-oriented innovations, and changing patterns of consumer engagement.

3.4 Digitalisation and Innovation in the Spanish Wine Sector

Digitalisation and innovation are profoundly transforming the Spanish wine sector, driving structural changes in key areas such as production, marketing, sustainability, and consumer relations. Although many Spanish wineries retain a family-based structure and a production tradition with relatively low technological intensity, the current context—characterised by growing globalisation and competitiveness—demands rapid adaptation to new digital tools and more innovative management models. This evolution responds not only to market requirements but also to the challenges of climate change and new social expectations regarding sustainability.

Among the emerging trends shaping the sector are the growing demand for organic wines—still mostly export-driven—and the rapid expansion of new categories such as low-alcohol and non-alcoholic wines, especially among young urban consumers. The e-commerce channel is anticipated to continue gaining ground, while traditional retail loses relevance. In addition, wine tourism is set to play an increasingly important role as a means of diversifying revenue streams and building stronger brand connections with consumers, becoming vital for small and medium-sized wineries seeking direct engagement with their markets (Vinetur, 2025).

These transformations show how innovation is increasingly linked to changing consumer preferences and market dynamics. At the core of this process lies the adoption of digital strategies and marketing tools, which enable wineries to strengthen visibility, connect directly with consumers, and expand into new sales channels. The next subsection therefore examines the role of digitalisation in marketing and communication as a first step in the broader innovation pathway of the Spanish wine sector.

3.4.1 Digital Strategies and Marketing

One of the fields where digitalisation has had the greatest impact is marketing and communication with consumers. In regions such as Catalonia, wineries belonging to designations of origin have begun to actively use social media as a primary channel to connect with their audiences, disseminate their values, and position their products. Nevertheless, this

process still faces major challenges, such as the need to improve digital literacy in rural communities, which is essential to ensure a more equitable and profound digital development within the sector (Mundet Pons et al., 2024).

Likewise, the online presence and reputation of Spanish wine cooperatives have proven to be influenced by several factors, including business integration, the attainment of organic certifications, export orientation, and the quality of their websites. These elements contribute significantly to enhancing their digital visibility and strengthening their competitiveness in a market increasingly shaped by online perceptions (Bernal-Jurado et al., 2021).

In this same context, the implementation of customer relationship management systems (CRM) has become a key indicator of wineries' predisposition to embrace digital transformation. However, many small and medium-sized enterprises still encounter barriers to incorporating such tools, due to limitations in resources, training, or technological infrastructure (Guerola-Navarro et al., 2021).

The growing incorporation of digital tools in marketing and customer management demonstrates not only the sector's capacity to adapt to new forms of communication, but also the need to address persistent gaps in adoption and implementation. These developments extend beyond the commercial sphere, as they increasingly influence the way wineries design their strategies, structure their operations, and position themselves within the market. This evolution, therefore, sets the stage for broader processes of innovation and business transformation, which are essential for ensuring long-term competitiveness in the wine sector.

3.4.2 Innovation and Business Transformation

Technological innovation extends beyond marketing, as it is also redefining business models within the framework of the transition towards Industry 4.0. This shift entails the integration of basic digital capabilities and the promotion of intersectoral cooperation, with the aim of developing more flexible, sustainable, and customer-centred solutions. Wineries are being driven to rethink their internal structures and open themselves to new forms of collaboration to remain relevant (Dressler, 2020).

In the field of wine tourism, this transformation is also clearly evident. Increasingly, wineries are adopting technologies such as augmented reality, virtual reality, e-commerce, and

intelligent management systems in order to enrich visitor experience, diversify revenue streams, and consolidate their commitment to sustainability.
In this way, wine tourism becomes not only a commercial tool but also a pathway for communicating innovation and the responsible practices adopted by the sector (Piras, 2024). Nevertheless, innovation in the wine industry is not limited to technological or organisational dimensions; its significance increasingly lies in how it fosters environmental performance and contributes to the green transition. This interdependence between innovation and sustainability represents a crucial dimension for the future of the sector, and it is the focus of the following subsection.

3.4.3 Sustainability and Green Innovation

The link between innovation and sustainability is becoming increasingly consolidated in the digital transformation strategies of the wine sector. A determining factor in this process is green transformational leadership, which, together with employee motivation, constitutes a key driver of sustainable innovation within Spanish wineries. Organisational culture, especially when it promotes ecological values, facilitates the adoption of clean technologies and more environmentally responsible practices (Sánchez-Garcia et al., 2023).

Indeed, evidence shows that there is a positive relationship between digitalisation and performance in green innovation. This relationship is mediated by factors such as the internal sharing of ecological knowledge and the environmental awareness of top management. In this respect, digitalisation not only acts as an operational tool but also as a catalyst for more profound change in business mindsets (Martínez Falcó et al., 2024).

It is important to emphasise that, beyond the technological or financial resources available, what truly makes a difference in terms of sustainability is the capacity to innovate and to effectively communicate such innovation. Wineries that succeed in linking their technological progress to a convincing narrative of sustainability and environmental commitment tend to generate greater value, both in economic terms and in terms of reputation (García-Cortijo et al., 2021).

Ultimately, the effectiveness of green and digital innovation is conditioned by evolving consumer expectations. Preferences for organic production, transparency, and sustainable wine tourism increasingly shape how wineries define their strategies and communicate their values. These shifts in demand thus emerge as a decisive force in driving transformation within the sector, a dynamic explored in the following subsection.

3.5 Changes in Wine Consumer Behaviour

The wine sector's digital transformation is also a response to a substantial change in consumer behaviour. In Spain, wine consumers are increasingly exploratory, informed, and demanding. They seek not only product quality but also coherence between a brand's values, its environmental impact, and its approach to digital interaction (Muñoz et al., 2019).

In the face of this new reality, wineries are compelled to adapt through intensive use of digital technologies, not only to improve their visibility and commercial efficiency but also to create more personalised and sustainable experiences. Emotional connection with the consumer, enhanced through digital storytelling, thus becomes a key factor of differentiation

Once the economic significance and heterogeneity of the sector have been characterised, it becomes essential to examine in depth the level of sustainability achieved by Spanish wineries and the specific measures adopted to reduce their environmental footprint. This new section focuses on identifying the progress, trends, and challenges in the implementation of mitigation and adaptation strategies to climate change, providing evidence of recent developments in practices, certifications, and sectoral outcomes.

4 SECTOR REVIEW: DEGREE OF SUSTAINABILITY AND ADOPTION OF MITIGATION MEASURES IN SPANISH WINERIES

In recent years, the Spanish wine sector has made remarkable progress in implementing sustainability and climate change mitigation strategies. This evolution responds not only to new regulatory requirements but also to a growing market preference for sustainable wines. Key milestones include the widespread adoption of the Sustainable Wineries for Climate Protection (SWfCP) seal and the steady growth of EU Organic Certification, which together evidence a tangible shift toward more resilient, responsible, and internationally competitive production models.

In parallel, Spain leads organic viticulture at the European level: in 2024, 166,285 hectares of vineyards were certified as organic—representing approximately 18% of the national vineyard area—and 1,334 wineries and bottlers were registered under EU legislation (FEV, 2024a).

The SWfCP standard, updated in 2023, integrates environmental, social, economic, and governance (ESG) criteria, providing a comprehensive and sector-adapted framework for sustainability benchmarking (Ecoterrae, 2023). Certified wineries must demonstrate continuous improvement across four areas: energy, water, waste, and emissions. The system is aligned with ISO 14001 and incorporates lifecycle analysis (LCA), enhancing its credibility and comparability. In parallel, organic certification leads to a reduced agrochemical footprint and improved biodiversity, solidifying Spain's leadership in low-input, environmentally resilient viticulture.

However, the sector's sustainable transition is advancing at two different speeds. On one hand, accessible practices like energy efficiency, selective waste management, and local sourcing are now standard for most wineries, delivering immediate environmental and reputational benefits and being highly replicable. On the other hand, more advanced solutions—such as biochar valorization, integrated water–energy management, or fleet electrification—still show relatively low adoption, limited mainly to pioneering wineries with higher investment capacity. This gap is primarily due to economic and technological factors, which underscores the need for policies and incentives specifically adapted to the sector's heterogeneous reality.

Case studies show that certified wineries have achieved tangible results. For example, Familia Torres has reported a 40% reduction in CO_2 emissions per bottle throughout its entire value chain—from vineyard to consumer—in 2024 compared to 2008, the year they began measuring their carbon footprint. Even more remarkable is the nearly 60% reduction in direct emissions (scopes 1 and 2), based on an independently audited 2024 report, marking significant progress in their decarbonization process. These improvements were possible due to measures such as installation of photovoltaic panels, biomass boilers, electrification of their vehicle fleet, and holistic initiatives under the "Torres & Earth" climate action plan, involving over €23 million in investments since 2008 in renewable energy, sustainable mobility, water management, and regenerative viticulture (Familia Torres, 2025).

Beyond Torres, other Spanish wineries exemplify the sector's commitment to sustainability. Entrecanales Domecq e Hijos has embedded sustainability into its business model, achieving SWfCP certification for its wineries Cosme Palacio (DOCa Rioja) and Caserío de Dueñas (DO Rueda), while its Viña Mayor (DO Ribera del Duero) has been carbon neutral since 2017. The group has also launched a Sustainability Plan with 100 initiatives between 2023 and 2027 (Harpers, 2023). Similarly, Familia Martínez Zabala, through its Bodegas Campillo (DOCa

Rioja) and Bodegas Portia (DO Ribera del Duero), has achieved SWfCP certification, strengthening its ESG-aligned strategy (Familia Martínez Zabala, 2024).

In DO Rueda, Bodegas Marqués de Cáceres introduced measures such as solar panel installation, energy-efficient equipment upgrades, reuse of treated water for irrigation, bottle weight reduction, and a shift to sustainable packaging, which collectively enabled SWfCP certification (Marqués de Cáceres, 2024). Likewise, Costers del Sió (Lleida) obtained certification in 2025, backed by Spain's Recovery, Transformation, and Resilience Plan, underlining the relevance of public-private partnerships in propelling the sustainability transition (Costers del Sió, 2025).

In southeastern Spain, Bodegas Luzón (DO Jumilla) renewed its SWfCP certification in 2024, after pioneering environmental practices such as ISO 14001 adoption, natural winemaking techniques, efficient water management, and lighter bottles (Grupo Fuertes, 2024). These cases illustrate the diverse strategies by which wineries nationwide are progressing in sustainability, adapted to their regional contexts and business models, yet aiming for common objectives of decarbonisation, efficiency, and resilience.

Importantly, this momentum is evident in the numbers: SWfCP-certified wineries grew from 103 in 2024 (Vinetur, 2024) to 127 by mid-2025 (Vinos de Castilla-La Mancha, 2025), showcasing the rapid uptake of sustainability certification and reinforcing the sector's commitment to environmental stewardship and climate action.

Furthermore, the expansion of green finance agreements—such as those involving the Spanish Wine Federation and BBVA—has facilitated investment in renewable energy technologies, monitoring systems, and infrastructure retrofitting (FEV, 2024b). These dynamics reflect how a growing number of wineries are not only aware of their climate impact, but are also actively transforming their operations to achieve effective long-term resilience.

4.1 Barriers to Sustainability Implementation

Despite these encouraging developments, several structural, economic, and cultural barriers persist that hinder the widespread adoption of mitigation strategies, particularly among small and medium-sized enterprises (SMEs) that dominate the Spanish wine sector.

Economic constraints are among the most cited limitations. Initial capital investment required for technologies such as solar PV systems, heat pumps, reverse logistics, or advanced monitoring tools (e.g., for irrigation precision or energy management) remains inaccessible to many small producers without significant public co-financing (De Castro et al., 2024).

Furthermore, the cost and administrative burden of maintaining SWfCP or EU Organic certification can be disproportionately high for smaller wineries with limited staff and technical capacity.

Cultural resistance also plays a role, especially in regions with strong winemaking traditions. Many consumers still equate heavy glass bottles with premium wine quality, which hampers the transition toward lightweight or alternative packaging formats (Ponstein et al., 2019; Mura et al., 2023). Similarly, skepticism toward non-traditional practices—such as cover cropping or minimal tillage—can delay the adoption of regenerative approaches in conventional vineyards.

Technical limitations further constrain implementation. Older infrastructures in many Spanish wineries lack the flexibility for rapid retrofitting. Moreover, precision agriculture technologies require training and ongoing data analysis, which not all operators can afford or access. The limited availability of qualified agronomists and energy consultants with specific expertise in wine systems represents a knowledge bottleneck (Niccolucci et al., 2025).

Regulatory fragmentation also complicates the integration of sustainability practices. The absence of harmonized carbon accounting frameworks and lifecycle analysis methods at the EU level means that wineries are often confronted with varying criteria from buyers, certifiers, and public agencies, making it difficult to plan consistent long-term sustainability strategies (Wagner et al., 2023).

To overcome these barriers, stakeholders call for enhanced public-private collaboration, expanded technical assistance programs, and targeted incentives for SMEs to ensure that the transition is inclusive and scalable. Without this systemic support, the risk persists that only large or export-oriented wineries will be able to fully integrate sustainability, exacerbating inequality within the sector.

4.2 Key Mitigation Measures Identified in the Sector

The Spanish wine sector has progressively implemented mitigation strategies in line with the EU Green Deal and private certifications such as the Sustainable Wineries for Climate Protection scheme, developed by the Spanish Wine Federation with technical support from AENOR (SOCOTEC, 2024)

Energy efficiency remains one of the most adopted lines of action. Wineries have undertaken energy audits and retrofitted operations with LED systems, automated temperature control for fermentation, and efficient HVAC equipment. These efforts aim to reduce energy intensity, a key emissions source in post-harvest stages (OIV, 2020b).

The integration of renewable energy—especially photovoltaic systems—has gained momentum, with many wineries installing solar panels either for self-consumption or hybrid models combined with net-metering. This aligns with EU targets for carbon neutrality and reduces dependence on fossil fuels. As of 2024, Spanish Wine Federation reports a steady increase in wineries leveraging EU-funded support for renewable deployment under NextGenerationEU funds (FEV, 2024b).

CO_2 capture and valorisation is emerging as a strategic frontier, particularly in fermentation-related emissions. Pilot projects are being developed to collect fermentation CO_2 and reuse it in winery processes, such as inerting tanks or in carbonation of other beverages. Though still incipient, these technologies point toward a circular carbon model in enology (OIV, 2022b).

Water management practices are also central to mitigation. Precision irrigation systems, humidity and evapotranspiration sensors, and deficit irrigation strategies are increasingly adopted, particularly in regions facing water scarcity like Castilla-La Mancha or Murcia. The digitalization of water control is helping align with sustainable viticulture models and EU Water Framework Directive goals (MAPA, 2023)

Circular economy principles have also permeated wine production, particularly through by-product valorisation. Organic residues such as grape marc, lees, and stems are being processed into biofertilizers, cosmetics, and even bioplastics. Spanish Wine Federation indicates that more than 70% of large wineries have some form of residue recovery protocol in place (FEV, 2024).

Finally, sustainable viticultural practices such as cover cropping, reduced tillage, agroecological corridors, and the promotion of biodiversity are being mainstreamed. These contribute not only

to carbon sequestration and erosion control but also to enhancing resilience to extreme weather events (Ferrer et al., 2023b).

4.3 Benefits and Advantages of Mitigation Measures Implementation

The implementation of mitigation strategies in the Spanish wine sector has delivered multidimensional benefits, showing that sustainability and profitability can coexist when actions are strategically aligned with business objectives.
Economically, wineries adopting sustainable measures report lower energy and water bills, improved access to public support, and better market positioning. According to the Spanish Wine Federation, the Sustainable Wineries for Climate Protection (SWfCP) seal is recognised by several purchasing organisations (e.g., Nordic alcohol monopolies) and retailers such as Aldi and Lidl—an acceptance that can favour certified wineries in procurement processes (FEV, 2024c).

Environmentally, reductions in greenhouse gas emissions are significant, especially among those wineries that deploy on-site renewables and energy efficiency upgrades. For instance, the case of Familia Torres is emblematic: in 2024, Wine Intelligence reported that the winery achieved a 40% reduction in CO_2 emissions per bottle across its value chain (from vineyard to consumer) compared to 2008 levels, along with an almost 60% decrease in direct emissions (scopes 1 & 2) (Wine Intelligence, 2025). These achievements were enabled by investing in photovoltaic panels, biomass boilers, and electrifying the vehicle fleet, reinforcing the feasibility of combining decarbonization and operational improvements within the same business strategy Socially and reputationally, sustainability credentials have become key differentiators. Spain counts 1,334 organic wineries and bottlers operating under EU organic rules (latest sectoral update), while the upgraded SWfCP scheme (2022) has been adopted by over 100 Spanish wineries as of May 2024, strengthening branding and consumer trust in export markets (OIVE, 2025).

The literature further suggests that sustainability-oriented wineries tend to build stronger stakeholder relationships, foster internal innovation, and enhance organisational resilience when mitigation is treated as a competitive advantage rather than mere compliance (Ferrer et al., 2023a).

Finally, while prior reports help identify barriers, benefits, and drivers, few studies offer representative, nationwide evidence encompassing Spain's regional and corporate diversity.

The following section therefore presents an exploratory survey of Spanish wineries to provide an up-to-date and realistic view of sustainability and mitigation uptake across the sector.

5 EMPIRICAL ASSESSMENT OF SUSTAINABILITY IN SPANISH WINERIES: EVIDENCE FROM A SURVEY STUDY

Building upon the trends and challenges identified in the preceding chapter, this chapter presents the results of the empirical study conducted among Spanish wineries. The aim is to determine the actual degree of implementation, barriers and benefits, thereby enabling a comparison between the international/theoretical context and the Spanish reality

5.1 Survey Design and Structure

To design the survey, a preliminary literature review was conducted focusing on the economic structure of the wine sector, market data, the organization and dynamics of wineries, as well as aspects related to sustainability in the sector. This review helped identify both the main barriers and the drivers that motivate companies to implement sustainable strategies in their vineyards or wineries.

Simultaneously, deliverable D.5.2—a catalogue of sustainable measures—was being developed, which also served as a basis for the survey design, as it compiled and analysed various practices applicable to the sector.

The survey was structured into four sections:

- Environmental Commitment
- Implementation of Sustainable Strategies: Barriers and Benefits
- Decision-Making Processes for the Adoption of Sustainable Strategies
- General Information about the Winery

The first section contains closed-ended (yes/no) questions that help characterize the winery based on its size and its commitment to sustainability. The second section focuses on understanding the degree of implementation of sustainable strategies in the winery through multiple-choice questions. It also includes, again through multiple-choice format, questions on the main barriers encountered during implementation and the benefits already obtained or expected. The third section gathers information about the decision-making process that led winery managers to adopt sustainable measures, aiming to identify the most influential factors

in that choice (multiple-choice questions). Finally, the fourth section requests general information about the winery, such as its location, number of employees, and other relevant data.

5.2 Sampling Design and Methodology

To design the sample and select the type of sampling used, the first step was to determine the population of wineries to be analysed. According to the most recent data available in the SABI database, which compiles information on Spanish and Portuguese companies, the Spanish wine sector is currently made up of 3,925 wineries distributed unevenly across the 17 autonomous communities. The regions with the largest number of wineries are Cataluña (598), Castilla y León (596), Galicia (390), La Rioja (313), Castilla-La Mancha (357), País Vasco (356), and Andalucía (312), which together concentrate more than two-thirds of the national total. In contrast, regions such as Asturias (17) and Cantabria (17) show a much smaller number of wineries.

In order to maximize representativeness while simplifying the sampling procedure, a stratified random sampling by autonomous community was adopted. This stratification ensures that all wine-producing regions are included, avoiding over-representation of those with the highest number of wineries and guaranteeing coverage of smaller wine regions.

The calculation of sample size depends, as is standard, on the confidence level and margin of error selected. With a confidence level of 95% and a margin of error of 5%, the required sample size for wineries is 350. In contrast, if a less demanding alternative is chosen, with 90% confidence and 10% error, the minimum sample size is reduced to 67 wineries.

Based on this, the proportional distribution of the sample across autonomous communities was carried out using the most recent number of wineries in each region (see Table 3). This approach ensures that the sample reflects the real structure of the Spanish wine sector, in which the weight of each region is very heterogeneous. For instance, Cataluña, Castilla y León, and Castilla-La Mancha constitute the main strata, as they are by far the largest producing regions. In contrast, regions with a much smaller number of wineries, such as Asturias or Cantabria, are represented by very small subsamples, strictly proportional to their actual size within the population. In the most restrictive sampling scenario (90% confidence and 10% margin of error), the reduced overall sample size (67 wineries) results in these smaller regions not being represented at all, which reflects their marginal presence in the national industry.

Table 3. Sample of the study

Region	Number of Wineries	Sample 95% Confidence – 5% Margin of Error	Sample 90% Confidence – 10% Margin of Error	Current Sample
Aragón	125	11	2	3
Andalucía	312	28	5	3
Asturias	17	1	0	1
Baleares	96	9	2	1
Canarias	124	11	2	1
Cantabria	17	1	0	0
Castilla y León	596	53	10	9
Castilla-La Mancha	357	32	6	3
Cataluña	598	53	10	9
Comunidad Valenciana	198	18	4	4
Extremadura	112	10	2	1
Galicia	390	35	7	3
La Rioja	313	28	5	5
Madrid	165	15	3	2
Murcia	61	5	1	1
Navarra	88	8	2	2
País Vasco	356	32	6	1
Total	3925	350	67	49

At the current stage of the research, the number of responses obtained remains limited, with completed surveys from 49 wineries. While this sample does not reach the thresholds required for strict statistical representativeness at either the national or regional level, it nonetheless covers 16 of the 17 autonomous communities, encompassing both large wine-producing regions and smaller ones.

This breadth of coverage ensures that, despite its size, the sample is sufficiently diverse to capture the main dynamics shaping the sector. The findings should therefore be interpreted with caution—particularly when making regional comparisons—but they provide a valuable and credible overview of how Spanish wineries are addressing sustainability and climate change mitigation.

The results presented here should be seen as exploratory yet meaningful, offering an indicative snapshot of the current situation. As additional responses are gathered, the analyses and conclusions will be revised and strengthened to enhance the representativeness of the study.

5.3 Survey Results

5.3.1 Profile of the Wineries in the Sample

A large majority of wineries in the sample (close to 90%) own their own vineyards, with an average size of around 255 hectares. This figure is accompanied by a very high standard deviation (612 hectares), which underscores the strong variability in vineyard size across wineries, ranging from small, family-run plots to large-scale estates. This highlights the dual agricultural and oenological character of Spanish wineries, where viticulture and winemaking are often closely integrated.

Beyond grape cultivation, many wineries diversify their activities through complementary initiatives. The most prominent is wine tourism (67%), practiced by two-thirds of the sample, encompassing visits, tastings, and accommodation services. Other relevant activities include the management of forest areas and natural conservation projects (35%), renewable energy production for commercial sale (18%), and the elaboration of other agri-food products such as cheese or honey (6%). A smaller proportion engage in livestock farming (4%) or in educational and cultural initiatives (18%). In contrast, nearly one in five wineries declare that they do not pursue any activity beyond wine production, reflecting the sector's heterogeneous diversification strategies.

The workforce profile also illustrates this heterogeneity. On average, wineries employ about 72 full-time workers (SD = 194) and 9 seasonal employees (SD = 16). These wide standard deviations reveal significant dispersion in employment structures, with the coexistence of small family wineries operating with minimal staff and larger companies with highly developed organizational frameworks.

Quality certification emerges as another defining characteristic of the sample. The vast majority of wineries (84%) produce under a Designation of Origin (DO), while 20% are affiliated with the more prestigious Qualified Designation of Origin (DOCa). Smaller proportions operate under other categories such as Vino de Pago (2%), Vino de Calidad with Geographical

Indication (2%), or Vino de la Tierra (10%). Only 4% of wineries report not being associated with any quality certification scheme.

Overall, these findings portray a sector strongly anchored in vineyard ownership and quality certification, increasingly diversified through complementary activities such as enotourism and environmental management, and marked by considerable structural heterogeneity. This diversity provides both opportunities and challenges for advancing sustainability and climate change mitigation strategies in the Spanish wine industry.

5.3.2 Adoption level of mitigation measures among surveyed wineries

Apply reduced tillage techniques
59.2% of wineries are already applying this measure, while 12.2% have evaluated it but are not planning to implement it. 12.2% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 12.2% are currently in the process of adoption.

Incorporate pruning wood into the soil
75.5% of wineries are already applying this measure, while 10.2% have evaluated it but are not planning to implement it. 6.1% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 8.2% are currently in the process of adoption.

Incorporate purchased biochar into the soil
12.2% of wineries are already applying this measure, while 22.4% have evaluated it but are not planning to implement it. 44.9% report needing more information, and 8.2% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 10.2% are currently in the process of adoption.

Incorporate biochar produced in the winery into the soil
14.3% of wineries are already applying this measure, while 18.4% have evaluated it but are not planning to implement it. 49.0% report needing more information, and 6.1% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 10.2% are currently in the process of adoption.

Incorporate purchased composted biochar into the soil
14.3% of wineries are already applying this measure, while 26.5% have evaluated it but are not planning to implement it. 42.9% report needing more information, and 4.1% state they are

neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 8.2% are currently in the process of adoption.

Incorporate composted biochar produced in the winery into the soil

10.2% of wineries are already applying this measure, while 22.4% have evaluated it but are not planning to implement it. 49.0% report needing more information, and 4.1% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 10.2% are currently in the process of adoption.

Substitute synthetic fertilizers through crop rotation

36.7% of wineries are already applying this measure, while 22.4% have evaluated it but are not planning to implement it. 30.6% report needing more information, and 4.1% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 6.1% are currently in the process of adoption.

Change land use to regenerative vineyards

36.7% of wineries are already applying this measure, while 16.3% have evaluated it but are not planning to implement it. 30.6% report needing more information, and 4.1% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 8.2% are currently in the process of adoption.

Cultivate grapevine varieties resistant to pests and extreme climate

32.7% of wineries are already applying this measure, while 20.4% have evaluated it but are not planning to implement it. 22.4% report needing more information, and 4.1% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 18.4% are currently in the process of adoption.

Create climate shelters to protect crops from adverse conditions

16.3% of wineries are already applying this measure, while 16.3% have evaluated it but are not planning to implement it. 36.7% report needing more information, and 8.2% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 22.4% are currently in the process of adoption.

Apply fertilizer through irrigation (fertigation)

40.8% of wineries are already applying this measure, while 26.5% have evaluated it but are not planning to implement it. 18.4% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 12.2% are currently in the process of adoption.

Maintain natural predators for pest control

59.2% of wineries are already applying this measure, while 10.2% have evaluated it but are not planning to implement it. 16.3% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 12.2% are currently in the process of adoption.

Use sexual confusion techniques for pest control

65.3% of wineries are already applying this measure, while 10.2% have evaluated it but are not planning to implement it. 8.2% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 12.2% are currently in the process of adoption.

Optimize phytosanitary treatments with digital tools

46.9% of wineries are already applying this measure, while 14.3% have evaluated it but are not planning to implement it. 14.3% report needing more information, and 2.0% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 18.4% are currently in the process of adoption.

Manage soil with plant cover

61.2% of wineries are already applying this measure, while 18.4% have evaluated it but are not planning to implement it. 12.2% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 8.2% are currently in the process of adoption.

Plant multifunctional margins along borders and roadsides

40.8% of wineries are already applying this measure, while 22.4% have evaluated it but are not planning to implement it. 18.4% report needing more information, and 2.0% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 16.3% are currently in the process of adoption.

Promote multifunctional margins through natural regeneration

55.1% of wineries are already applying this measure, while 16.3% have evaluated it but are not planning to implement it. 12.2% report needing more information, and 2.0% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 14.3% are currently in the process of adoption.

Install vegetative barriers against erosion and wind

46.9% of wineries are already applying this measure, while 22.4% have evaluated it but are not planning to implement it. 12.2% report needing more information, and 2.0% state they are

neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 14.3% are currently in the process of adoption.

Apply organic mulching

38.8% of wineries are already applying this measure, while 22.4% have evaluated it but are not planning to implement it. 18.4% report needing more information, and 2.0% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 16.3% are currently in the process of adoption.

Implement agroforestry systems with brush cutters

49.0% of wineries are already applying this measure, while 22.4% have evaluated it but are not planning to implement it. 12.2% report needing more information, and 4.1% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 12.2% are currently in the process of adoption.

Implement agroforestry systems with animal grazing

18.4% of wineries are already applying this measure, while 40.8% have evaluated it but are not planning to implement it. 20.4% report needing more information, and 8.2% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 12.2% are currently in the process of adoption.

Use free-training conduction systems

18.4% of wineries are already applying this measure, while 32.7% have evaluated it but are not planning to implement it. 32.7% report needing more information, and 6.1% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 8.2% are currently in the process of adoption.

Harvest and reuse rainwater

40.8% of wineries are already applying this measure, while 18.4% have evaluated it but are not planning to implement it. 16.3% report needing more information, and 2.0% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 18.4% are currently in the process of adoption.

Reuse wastewater through purification

30.6% of wineries are already applying this measure, while 22.4% have evaluated it but are not planning to implement it. 20.4% report needing more information, and 2.0% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 20.4% are currently in the process of adoption.

Install an agroclimatic station for real-time meteorological data
63.3% of wineries are already applying this measure, while 10.2% have evaluated it but are not planning to implement it. 6.1% report needing more information, and 2.0% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 16.3% are currently in the process of adoption.

Implement high-efficiency drip irrigation
67.3% of wineries are already applying this measure, while 8.2% have evaluated it but are not planning to implement it. 12.2% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 12.2% are currently in the process of adoption.

Sensor soil moisture
36.7% of wineries are already applying this measure, while 14.3% have evaluated it but are not planning to implement it. 16.3% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 28.6% are currently in the process of adoption.

Automate and optimize irrigation with smart technology
30.6% of wineries are already applying this measure, while 22.4% have evaluated it but are not planning to implement it. 18.4% report needing more information, and 2.0% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 24.5% are currently in the process of adoption.

Analyse hyperspectral and satellite images
24.5% of wineries are already applying this measure, while 22.4% have evaluated it but are not planning to implement it. 28.6% report needing more information, and 4.1% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 18.4% are currently in the process of adoption.

Monitor plant water status
28.6% of wineries are already applying this measure, while 18.4% have evaluated it but are not planning to implement it. 26.5% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 22.4% are currently in the process of adoption.

Store renewable energy in ponds for irrigation
30.6% of wineries are already applying this measure, while 22.4% have evaluated it but are not planning to implement it. 24.5% report needing more information, and 8.2% state they are

neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 14.3% are currently in the process of adoption.

Implement efficient energy control of pumps and irrigation
36.7% of wineries are already applying this measure, while 14.3% have evaluated it but are not planning to implement it. 22.4% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 24.5% are currently in the process of adoption.

Improve the efficiency of the winery's cooling system
55.1% of wineries are already applying this measure, while 10.2% have evaluated it but are not planning to implement it. 14.3% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 18.4% are currently in the process of adoption.

Use groundwater as a heat exchanger for cooling and air conditioning
6.1% of wineries are already applying this measure, while 36.7% have evaluated it but are not planning to implement it. 36.7% report needing more information, and 6.1% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 12.2% are currently in the process of adoption.

Reduce winery lighting consumption through LED and smart management
79.6% of wineries are already applying this measure, while 4.1% have evaluated it but are not planning to implement it. 2.0% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 14.3% are currently in the process of adoption.

Reduce thermal demand with thermal insulation
71.4% of wineries are already applying this measure, while 8.2% have evaluated it but are not planning to implement it. 8.2% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 12.2% are currently in the process of adoption.

Reduce thermal demand with bioclimatic construction
24.5% of wineries are already applying this measure, while 20.4% have evaluated it but are not planning to implement it. 30.6% report needing more information, and 4.1% state they are neither using it nor planning to do so. Meanwhile, 6.1% express interest in adopting it in the future, and 14.3% are currently in the process of adoption.

Implement building energy control (climate, temperature, etc.)
53.1% of wineries are already applying this measure, while 10.2% have evaluated it but are not planning to implement it. 14.3% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 18.4% are currently in the process of adoption.

Unify energy management of vineyard, winery and transport with smart systems
12.2% of wineries are already applying this measure, while 20.4% have evaluated it but are not planning to implement it. 36.7% report needing more information, and 6.1% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 22.4% are currently in the process of adoption.

Replace fossil irrigation generators with photovoltaic systems
46.9% of wineries are already applying this measure, while 18.4% have evaluated it but are not planning to implement it. 12.2% report needing more information, and 2.0% state they are neither using it nor planning to do so. Meanwhile, 6.1% express interest in adopting it in the future, and 14.3% are currently in the process of adoption.

Replace fossil agricultural machinery with renewable electric machinery
12.2% of wineries are already applying this measure, while 30.6% have evaluated it but are not planning to implement it. 26.5% report needing more information, and 2.0% state they are neither using it nor planning to do so. Meanwhile, 8.2% express interest in adopting it in the future, and 20.4% are currently in the process of adoption.

Contract renewable electricity supply
53.1% of wineries are already applying this measure, while 2.0% have evaluated it but are not planning to implement it. 18.4% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 6.1% express interest in adopting it in the future, and 20.4% are currently in the process of adoption.

Incorporate photovoltaic self-consumption in the winery
65.3% of wineries are already applying this measure, while 2.0% have evaluated it but are not planning to implement it. 4.1% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 26.5% are currently in the process of adoption.

Replace heating and sanitary hot water boiler with geothermal energy
10.2% of wineries are already applying this measure, while 40.8% have evaluated it but are not planning to implement it. 28.6% report needing more information, and 8.2% state they are

neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 10.2% are currently in the process of adoption.

Replace heating and sanitary hot water boiler with aerothermal energy
12.2% of wineries are already applying this measure, while 38.8% have evaluated it but are not planning to implement it. 28.6% report needing more information, and 2.0% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 14.3% are currently in the process of adoption.

Replace fossil heating and sanitary hot water systems with solar thermal energy
24.5% of wineries are already applying this measure, while 22.4% have evaluated it but are not planning to implement it. 20.4% report needing more information, and 6.1% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 22.4% are currently in the process of adoption.

Replace fossil heating and sanitary hot water systems with biomass
14.3% of wineries are already applying this measure, while 38.8% have evaluated it but are not planning to implement it. 26.5% report needing more information, and 6.1% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 10.2% are currently in the process of adoption.

Install agrophotovoltaics
16.3% of wineries are already applying this measure, while 26.5% have evaluated it but are not planning to implement it. 34.7% report needing more information, and 4.1% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 14.3% are currently in the process of adoption.

Use renewable fuels in transport vehicles
18.4% of wineries are already applying this measure, while 32.7% have evaluated it but are not planning to implement it. 28.6% report needing more information, and 2.0% state they are neither using it nor planning to do so. Meanwhile, 6.1% express interest in adopting it in the future, and 12.2% are currently in the process of adoption.

Electrify vehicle fleet and charge with renewable energy
20.4% of wineries are already applying this measure, while 22.4% have evaluated it but are not planning to implement it. 24.5% report needing more information, and 2.0% state they are neither using it nor planning to do so. Meanwhile, 6.1% express interest in adopting it in the future, and 24.5% are currently in the process of adoption.

Manage and plan vehicle routes in the organization
38.8% of wineries are already applying this measure, while 12.2% have evaluated it but are not planning to implement it. 28.6% report needing more information, and 2.0% state they are neither using it nor planning to do so. Meanwhile, 6.1% express interest in adopting it in the future, and 12.2% are currently in the process of adoption.

Implement collective transport systems
36.7% of wineries are already applying this measure, while 20.4% have evaluated it but are not planning to implement it. 24.5% report needing more information, and 4.1% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 10.2% are currently in the process of adoption.

Prioritize purchasing from local suppliers
87.8% of wineries are already applying this measure, while 2.0% have evaluated it but are not planning to implement it. 2.0% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 6.1% are currently in the process of adoption.

Capture and reuse CO2 in processes such as pumping over or inerting
12.2% of wineries are already applying this measure, while 20.4% have evaluated it but are not planning to implement it. 40.8% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 22.4% are currently in the process of adoption.

Use refrigerants with low global warming potential
38.8% of wineries are already applying this measure, while 6.1% have evaluated it but are not planning to implement it. 32.7% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 18.4% are currently in the process of adoption.

Replace cleaning products with pressurized water or steam
77.6% of wineries are already applying this measure, while 2.0% have evaluated it but are not planning to implement it. 6.1% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 14.3% are currently in the process of adoption.

Reduce bottle glass weight
77.6% of wineries are already applying this measure, while 6.1% have evaluated it but are not planning to implement it. 6.1% report needing more information, and 0.0% state they are neither

using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 8.2% are currently in the process of adoption.

Reduce materials and weight in packaging
75.5% of wineries are already applying this measure, while 4.1% have evaluated it but are not planning to implement it. 10.2% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 10.2% are currently in the process of adoption.

Eliminate plastic or aluminum capsules
34.7% of wineries are already applying this measure, while 26.5% have evaluated it but are not planning to implement it. 14.3% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 4.1% express interest in adopting it in the future, and 20.4% are currently in the process of adoption.

Implement bottle reuse
26.5% of wineries are already applying this measure, while 32.7% have evaluated it but are not planning to implement it. 24.5% report needing more information, and 6.1% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 8.2% are currently in the process of adoption.

Replace cork with other bottle closures
69.4% of wineries are already applying this measure, while 4.1% have evaluated it but are not planning to implement it. 6.1% report needing more information, and 10.2% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 10.2% are currently in the process of adoption.

Apply sustainable purchasing criteria to products and services
73.5% of wineries are already applying this measure, while 2.0% have evaluated it but are not planning to implement it. 6.1% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 16.3% are currently in the process of adoption.

Use alternative packaging to glass
16.3% of wineries are already applying this measure, while 49.0% have evaluated it but are not planning to implement it. 18.4% report needing more information, and 10.2% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 6.1% are currently in the process of adoption.

Compost residues for commercialization
4.1% of wineries are already applying this measure, while 30.6% have evaluated it but are not planning to implement it. 42.9% report needing more information, and 4.1% state they are neither using it nor planning to do so. Meanwhile, 6.1% express interest in adopting it in the future, and 12.2% are currently in the process of adoption.

Produce biochar for commercialization
0.0% of wineries are already applying this measure, while 32.7% have evaluated it but are not planning to implement it. 51.0% report needing more information, and 10.2% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 6.1% are currently in the process of adoption.

Produce compost with biochar for commercialization
2.0% of wineries are already applying this measure, while 34.7% have evaluated it but are not planning to implement it. 49.0% report needing more information, and 8.2% state they are neither using it nor planning to do so. Meanwhile, 2.0% express interest in adopting it in the future, and 4.1% are currently in the process of adoption.

Transform residues into products such as cosmetics or biofertilizers
6.1% of wineries are already applying this measure, while 32.7% have evaluated it but are not planning to implement it. 46.9% report needing more information, and 4.1% state they are neither using it nor planning to do so. Meanwhile, 6.1% express interest in adopting it in the future, and 4.1% are currently in the process of adoption.

Separate residues selectively for recycling
83.7% of wineries are already applying this measure, while 0.0% have evaluated it but are not planning to implement it. 14.3% report needing more information, and 0.0% state they are neither using it nor planning to do so. Meanwhile, 0.0% express interest in adopting it in the future, and 2.0% are currently in the process of adoption.

5.3.3 Barriers to the adoption of mitigation measures

The most critical barrier reported by wineries is the high implementation cost, highlighted by 90.7% of respondents, which clearly represents the main obstacle for the sector. Technological or infrastructure limitations and lack of institutional or regulatory support were each mentioned by 67.4%, showing that structural and governance issues also weigh heavily. Low profitability was cited by 41.9%, while lack of information and knowledge was recognized by 39.5%. In contrast, barriers such as incompatibility with work processes (25.6%), difficulty of

stakeholder acceptance (16.3%), and especially incompatibility with the product image (4.7%) were much less frequently mentioned, suggesting they are secondary concerns compared to financial and infrastructural constraints.

5.3.4 Perceived benefits of adopting mitigation measures

On the positive side, wineries identified a wide range of benefits. The most frequently acknowledged were contribution to corporate social responsibility (CSR) (90.7%) and improvement of company image and reputation (88.4%), showing the strong value attached to reputation and social responsibility. Compliance with environmental regulations was also highly rated (81.4%), as was market differentiation (79.1%) and increased resilience to future climate risks such as droughts or frosts (76.7%). Market-related benefits were widely recognized: access to environmentally conscious market niches (69.8%) and improvement of wine quality (44.2%). From an economic standpoint, medium- to long-term cost savings and access to subsidies or green financing were both reported by 55.8% and 53.5% of wineries, respectively, highlighting that financial opportunities are perceived, though to a lesser extent than reputational and strategic advantages.

5.3.5 Motivations for implementing mitigation measures in Spanish wineries

The main motivations driving wineries to apply mitigation measures are related to regulatory compliance and anticipation of future regulations, both highlighted by 60.5% of the wineries. This indicates that the legal and regulatory framework is a key driver for climate action in the wine sector.

Environmental awareness emerges as the most widespread motivation, mentioned by 83.7% of wineries. In addition, 62.8% emphasize the importance of access to environmentally conscious consumers, showing that sustainability is also perceived as a factor of competitiveness in the market.

Other elements linked to economic incentives also play a relevant role. The possibility of accessing available grants or subsidies is recognized by 51.2% of wineries, while the option of reducing operating costs receives the same proportion (51.2%). Likewise, 44.2% consider that responding to stakeholder demands constitutes a significant motivation.

In contrast, the least influential motivations are participating in carbon offset or credit programs, acknowledged by only 18.6% of wineries, and following recommendations from

associations or cooperatives, mentioned by just 9.3%. These results suggest that wineries prioritize direct motivations (regulation, savings, consumers, environmental commitment) over more external or collective mechanisms.

5.3.6 Sources of information used by wineries before implementing mitigation and/or adaptation measures

Wineries rely primarily on technical studies or reports (62.8%) and on data obtained within the winery or vineyard (62.8%), related to climate, soils, water, or consumption. These direct and technical sources are among the most influential when it comes to supporting decision-making. Expert or advisor opinions (60.5%) and good practices already applied in the wine sector (60.5%) also carry significant weight, reflecting the importance of knowledge transfer and the trust placed in the experience of specialists and peers in the sector.

Opinions provided by stakeholders reach 53.5%, while specific requirements linked to environmental regulations or certifications influence 37.2% of wineries. These results show that both external pressure and the regulatory framework play a role, although less strongly than technical and sectoral sources.
In contrast, only 30.2% report having considered good practices carried out by competitors, and just 25.6% relied on information about how other organizations calculate their carbon footprint. Finally, a very small percentage (4.7%) indicate that they did not use any special information before deciding to implement measures, which suggests that most wineries base their decisions on some form of evidence or concrete reference.

5.3.7 Aspects that have influenced the decision to implement mitigation and/or adaptation measures

The most decisive factor highlighted by wineries is the cost of implementing the measure, which influences 67.4% of cases. Very close behind is the compatibility with existing processes and products, acknowledged by 65.1%, reflecting the importance of integrating measures without causing major disruptions in day-to-day operations.
The potential for emissions reduction also plays a relevant role, mentioned by 51.2% of wineries. In contrast, other technical or contextual aspects carry less weight: the ease of application influences 44.2%, while the visibility of short-term results is relevant for 41.9%.
Among the least influential factors are the level of acceptance within the community (25.6%) and the possibility of obtaining the necessary financing, mentioned by only 30.2%. Finally,

access to carbon credits and voluntary markets proves almost irrelevant, with just 2.3% of wineries considering it in their decision-making process.

5.3.8 People or groups that influenced the decision to implement mitigation and/or adaptation measures

The main actors influencing the decision of wineries are the internal technical team or workers, mentioned in 60.5% of cases, and the owners, highlighted by 51.2%. These results reflect that decision-making on sustainability largely depends on those directly involved in the operational and strategic management of the winery.
At a second level of influence are company managers (46.5%) and clients (37.2%), indicating that both business leadership and market pressure play a significant role, although less than that of internal staff and ownership.

Other external actors play a more limited role. Public administrations are recognized as influential by 20.9% of wineries, while sector organizations reach 18.6%. In the case of cooperative members, influence drops to 11.6%, and for the local community to just 7.0%. Finally, financial entities are barely mentioned, with only 4.7%, revealing their minimal relevance in the decision-making process.

5.3.9 Overall Sustainability Performance and Adoption Patterns

The results show that the level of agreement with the statement "The climate has changed" is very high, with an average score of 8.94 out of 10 and a standard deviation of 1.34. This means that the vast majority of wineries acknowledge climate change, with a high level of consensus and responses strongly concentrated in the upper end of the scale (9–10).

Regarding the willingness to reduce greenhouse gas emissions (CO_2 and others) generated in vineyards and wineries, the average score is also high, at 8.39, although accompanied by a larger standard deviation (2.17). This result indicates that, while most wineries express a clear willingness to reduce emissions, there are more pronounced differences among them: some show total commitment (10), while others fall in intermediate or even low values.

Overall, the data reflect that climate change is widely recognized in the wine sector and that there is a strong general willingness to act, although with greater diversity in the actual degree

of commitment to emissions reduction. This suggests that while awareness is firmly established, there are still varying levels of preparedness and capacity for action among wineries.

The results show that 44.9% of wineries calculate their carbon footprint, while only 14.3% calculate their water footprint. This reflects greater awareness and prioritization of greenhouse gas emissions over water use, even though both aspects are key to the sustainability of the sector.

Regarding the possession of sustainability certifications, 40.8% of wineries hold some type of accreditation. The most widespread is Sustainable Wineries for Climate Protection (SWfCP), present in 22.4% of wineries. This is followed by the EU Organic Certification (18.4%) and ISO 14001 (16.3%). Other certifications appear in very small proportions: Sustwine (Eco-Prowine) and Fair'n Green (4.1% each), and B Corp (2.0%). By contrast, no wineries reported having Regenerative Viticulture Alliance (RVA), Demeter Biodynamic Certification, or USDA Organic.

In addition to these structured certifications, some wineries reported other international seals or frameworks in open responses. Among them are JAS and Bio Suisse, linked to organic production in Japan and Switzerland; CCPAE, related to organic agriculture in Catalonia; and IWCA (International Wineries for Climate Action), a sector-specific initiative focused on reducing carbon emissions. Certifications and standards for environmental and energy management were also mentioned, such as ISO 50001, ISO 14064:2018, and the GHG Protocol, which strengthen the ability to measure, manage, and report wineries' climate performance.

Overall, the data reveal that although a significant proportion of wineries have begun to measure their environmental impact—mainly through the carbon footprint—and to obtain sustainability certifications, adoption remains uneven. National and European certifications are predominant, while international or more demanding standards are less widespread. However, the emergence of initiatives such as IWCA, ISO 50001, or GHG Protocol highlights the presence of a pioneering group of wineries seeking to differentiate themselves through advanced international standards, thereby reinforcing both their competitive positioning and their commitment to sustainability.

5.4 Conclusions

The results of this study provide a comprehensive picture of how Spanish wineries are addressing sustainability and climate change mitigation. The sector shows a strong awareness

of climate change, with most wineries acknowledging its reality and expressing a willingness to act and reduce greenhouse gas emissions. While consensus on the urgency of the issue is clear, differences remain in the level of actual commitment and capacity for action.

In terms of mitigation and adaptation measures, adoption is progressing but remains uneven. Traditional agronomic practices such as reduced tillage, cover crops, integrated pest management, or efficient irrigation systems are already well established, while more technologically advanced or resource-intensive solutions are still under consideration or in early stages of implementation. High costs and technological limitations continue to be the main barriers to broader adoption. At the same time, wineries recognize that the benefits extend beyond environmental outcomes, encompassing regulatory compliance, reputational gains, and strengthened corporate responsibility.

Motivations and influencing factors reflect this balance between constraints and opportunities. Decisions are primarily driven by regulatory requirements, environmental convictions, and market opportunities. Internal actors such as technical teams and owners play the most significant role in guiding these decisions, while external stakeholders such as administrations, sector organizations, or financial institutions exert comparatively less influence. Access to reliable information—through technical studies, in-house data, expert advice, and sectoral best practices—emerges as a crucial enabler of decision-making, while competitive dynamics or external benchmarks appear less decisive.
With regard to environmental accounting and certifications, progress is visible but partial. Carbon footprint assessments are becoming increasingly common, while water footprint calculations remain less widespread despite the importance of water in viticulture. Sustainability certifications are gradually expanding, with national and European schemes being the most prevalent. However, a smaller group of pioneering wineries is already aligning with international standards and demanding frameworks, signaling a forward-looking orientation and positioning themselves as leaders in the sector's climate transition.

Taken together, the findings suggest that Spanish wineries are at a decisive moment in their sustainability journey. Awareness and willingness to act are widespread, and there is a growing movement toward integrating mitigation measures, certifications, and monitoring systems. Yet, persistent financial, technical, and structural barriers indicate that the transition is still in progress rather than fully consolidated. Advancing this process will require stronger institutional support, better access to financing, and collective strategies that enable wineries to move from individual initiatives to systemic change.

The empirical analysis underscores the heterogeneity in the adoption of sustainable measures and the coexistence of both progress and barriers within the sector. On this basis, it is appropriate to prioritise strategies and practices according to their level of implementation and potential for scalability, thereby providing a roadmap tailored to the actual needs and capabilities of Spanish wineries. The following chapter presents a prioritisation methodology that translates sectoral experience into practical recommendations.

6 PRIORITIZATION OF MITIGATION AND ADAPTATION MEASURES BASED ON THEIR LEVEL OF ADOPTION

6.1 Methodological Approach to Ranking

The prioritization of mitigation and adaptation measures was carried out through a weighted scoring system based on the distribution of responses across different adoption categories. For each measure, wineries indicated whether they were currently using it, in the process of adopting it, planning to adopt it in the future, requiring more information before evaluating it, not using it and not planning to adopt it, or having already evaluated it but discarded its implementation.

Each of these categories was assigned a weight according to its relative proximity to actual adoption. The highest weight was given to the category "currently using," as it reflects consolidated practices. Intermediate weights were applied to the categories "not in use but adoption is in process" and "not in use but planning to adopt," as they signal a clear intention of uptake. A lower weight was assigned to the category "not in use, but more information is needed," which indicates uncertainty but preserves future potential. The lowest weights were assigned to "not in use and not planned to adopt" and "evaluated but not planned to adopt," as they reflect rejection or lack of interest in the measure.

For each measure, the percentage of responses in each category was multiplied by its corresponding weight, and the resulting values were aggregated into a single composite score. This score represents both the level of current implementation and the potential for future adoption. Finally, the measures were ranked from highest to lowest score, producing a prioritization list that reflects the practices most consolidated in the sector, those that are emerging, and those still marginal.

6.2 Ranking Results

The ranking provides a structured overview of how mitigation and adaptation measures are prioritized within Spanish wineries, reflecting both their current level of adoption and their potential for future uptake. The results clearly differentiate between measures that are already consolidated in winery operations, those that are emerging and gaining traction, and those that remain marginal or limited to pioneering actors.
The classification of measures falls into three broad groups according to adoption levels.

6.2.1 Group 1: Consolidated Practices (Ranks 1–20)

These measures are widely implemented and have become standard practice in many wineries. They are generally characterized by lower costs, high feasibility, and visible short-term benefits in terms of efficiency and sustainability. Representative practices include prioritizing local suppliers, reducing lighting consumption through LED and smart systems, selective waste separation, reducing glass and packaging weight, incorporating pruning residues into the soil, applying sustainable purchasing criteria, and installing photovoltaic self-consumption systems. Together, these reflect a strategy centered on efficiency gains, cost reductions, and reputational improvements.

6.2.2 Group 2: Emerging Practices (Ranks 21–46)

This group includes measures with moderate adoption that represent a transitional stage in the sector's sustainability pathway. They tend to require higher technological investments, organizational adjustments, or specific expertise. Examples include soil and crop monitoring with sensors, smart irrigation systems, bioclimatic building design, wastewater reuse, vegetative barriers, agroforestry measures, and the electrification of vehicle fleets. While not yet widespread, these practices are gradually gaining momentum and point to a more integrated and technology-driven model of sustainability.

6.2.3 Group 3: Nascent Practices (Ranks 47–68)

These measures remain at the margins of adoption, implemented only by pioneering wineries. They are typically associated with higher costs, experimental technologies, or structural changes in production systems. Examples include biochar use and commercialization,

agrivoltaics, geothermal and aerothermal heating systems, carbon capture and reuse, advanced composting strategies, and alternative packaging to glass. These practices embody long-term innovation potential, but face significant barriers to scaling up.

Overall, the ranking reveals a two-speed transition. On one hand, the consolidation of accessible and cost-effective practices demonstrates clear progress in embedding sustainability into daily operations. On the other, the slower uptake of advanced and disruptive practices highlights the challenges of moving from incremental efficiency measures to systemic transformation. These dynamic underscores both the achievements of the sector and the work still required to advance ambitious climate strategies.

Table 4. Ranking of Sustainable Measures in the Spanish Wine Sector by Level of Adoption

Mitigation measure	Score	Ranking
Prioritize purchasing from local suppliers	573,47	1
Reduce winery lighting consumption through LED and smart management	559,18	2
Replace cleaning products with water under pressure or steam	557,14	3
Selectively separate waste for recycling	555,10	4
Apply sustainable purchasing criteria for products and services	551,02	5
Incorporate photovoltaic self-consumption in the winery	546,94	6
Reduce the weight of glass in bottling	538,78	7,5
Reduce materials and weight in packaging	538,78	7,5
Incorporate pruning wood into the soil	522,45	9,5
Reduce thermal demand through thermal insulation	522,45	9,5
Implement high-efficiency irrigation: drip irrigation	510,20	11,5
Replace cork with alternative bottle closures	510,20	11,5
Use sexual confusion techniques for pest control	504,08	13
Contract electricity with renewable origin guarantee	502,04	14,5
Install an agroclimatic station to obtain real-time meteorological data	502,04	14,5
Maintain natural predators for pest control	483,67	16,5
Improve the efficiency of the winery's refrigeration system	483,67	16,5
Apply reduced tillage techniques	481,63	18
Implement energy control of the building (climatization, temperature, etc.)	479,59	19
Manage soil with plant cover	463,27	20
Promote multifunctional margins through natural regeneration	459,18	21
Optimize phytosanitary treatments through digital tools	451,02	22
Use refrigerants with low global warming potential	444,90	23
Sensor soil moisture	442,86	24
Replace fossil-fuel irrigation generators with photovoltaic systems	436,73	25
Implement energy-efficient control of pumps and irrigation	432,65	26
Install vegetative barriers against erosion and wind	424,49	27
Capture and use rainwater	424,49	28
Implement agroforestry systems with brushcutters	422,45	29
Manage and plan organizational vehicle routes	420,41	30
Plant multifunctional margins along borders and roadsides	408,16	31
Apply organic mulching	404,08	32
Sensor plant water status	397,96	33

Apply fertilizer through irrigation (fertigation)	395,92	34
Automate and optimize irrigation with smart technology	395,92	35,5
Eliminate plastic or aluminum capsules	395,92	35,5
Shift agricultural practices toward regenerative vineyards	393,88	37
Cultivate grapevine varieties resistant to pests and extreme climates	391,84	38
Implement collective transport systems	389,80	39,5
Reuse wastewater through treatment	389,80	39,5
Replace synthetic fertilizers through crop rotation	373,47	41
Replace fossil heating and hot water systems with solar thermal energy	371,43	42
Electrify the vehicle fleet and charge it with renewable energy	369,39	43
Store renewable energy in ponds for irrigation use	367,35	44
Analyze hyperspectral and satellite images	363,27	45,5
Reduce thermal demand with bioclimatic construction	363,27	45,5
Create climate shelters to protect crops against adverse conditions	353,06	47
Capture CO_2 and reuse it in processes such as remontage or inertization	344,90	48
Unify energy management of vineyard, winery, and transport through smart systems	336,73	49
Implement reuse of glass containers	326,53	50
Install agrivoltaic systems	324,49	51
Incorporate biochar into the soil, produced on the farm	322,45	52,5
Replace fossil agricultural machinery with renewable electric machinery	322,45	52,5
Use renewable fuels in transport vehicles	318,37	54
Incorporate biochar into the soil, purchased	306,12	56
Incorporate composted biochar into the soil, purchased	306,12	56
Incorporate composted biochar into the soil, produced on the farm	306,12	56
Use free-standing training systems	302,04	58
Implement agroforestry systems with livestock grazing	289,80	59,5
Replace heating and hot water boilers with aerothermal systems	289,80	59,5
Replace fossil heating and hot water systems with biomass	283,67	61
Compost waste for commercialization	277,55	62
Use groundwater as a thermal exchanger for cooling and climatization	265,31	63
Replace heating and hot water boilers with geothermal systems	263,27	64,5
Transform waste into products such as cosmetics or biofertilizers	263,27	64,5
Use alternative packaging to glass	253,06	66
Produce compost with biochar for commercialization	238,78	67
Produce biochar for commercialization	236,73	68

Having identified the measures with the highest level of adoption and potential within the sector, it is essential to analyse their feasibility and replicability in real-world contexts. To this end, the following section explores two exemplary pilot cases in greater depth, applying the Ecocanvas methodology to assess the environmental, economic, and social impacts of pioneering circular models in viticulture. These examples provide an integrated illustration of how the transition towards a circular economy can be realised within the wine sector

7 APPLICATION OF THE ECOCANVAS METHODOLOGY TO TWO CIRCULAR ECONOMY MEASURES UNDER THE LIFE CLIMAWIN PROJECT: DEMONSTRATION CASE AT THE BOSQUE DE MATASNOS WINERY

7.1 Introduction

Viticulture, a strategic sector in Mediterranean agri-food systems, faces growing pressures from climate change, water scarcity, rising energy costs, and the accumulation of organic residues. These challenges affect both the sustainability of vineyards and the resilience of wineries, demanding solutions that integrate soil, water, and energy management within circular models (Provenzano et al., 2024; Sacchelli et al., 2017; Skiba, 2025).

Circular economy approaches provide opportunities to transform environmental pressures into regenerative practices. In terms of soils and residues, the pyrolysis of vineyard prunings yields biochar, a stable material with high carbon sequestration potential and beneficial agronomic properties. When enriched with compost derived from winery and livestock by-products, biochar can enhance fertility, improve soil structure, and prolong carbon storage (Mujtaba et al., 2021; Liu et al., 2023). Such strategies contribute to reducing the sector's carbon footprint, production costs, and vulnerability to climate risks (Kovacs et al., 2022; Provenzano et al., 2024).

In parallel, the water–energy nexus has emerged as a critical dimension in viticulture. Access to water is essential for irrigation, sanitation, cooling, and biodiversity services, while its reuse and treatment require significant energy inputs. Studies on deficit irrigation, wastewater reuse, and renewable integration highlight both opportunities and risks—such as salinity accumulation—that must be carefully managed (Chaves et al., 2007; Reznik et al., 2019; Simhayov et al., 2023; Costa et al., 2020). Technological advances in photovoltaics, heat pumps, and wastewater reclamation point to new options, though most initiatives still approach water and energy separately (Chen et al., 2023; Blum et al., 2021).

The LIFE CLIMAWIN project responds to these challenges by piloting circular measures that valorise vineyard residues through compost-enriched biochar and establish self-sufficient water–energy systems. The case study, Bosque de Matasnos winery in Spain, illustrates how local resources can be integrated into systemic loops for soil regeneration, resource efficiency, and climate adaptation.

Both interventions are analysed using the Ecocanvas methodology, which maps circular business models across environmental, economic, and social dimensions (Daou et al., 2020; Bálint et al., 2025). By addressing biochar and water–energy strategies in parallel, the study contributes empirical evidence of their feasibility and replicability, aligning with the European

Green Deal, the Circular Economy Strategy, and the UN Sustainable Development Goals (6, 7, 12, 13).

7.2 The Ecocanvas Methodology for the Analysis of Circular Models

7.2.1 Ecocanvas Framework as Guiding Approach

To complement the survey-based results, this section presents an applied analysis of mitigation measures tested in the LIFE CLIMAWIN pilot winery. The Ecocanvas methodology (Cerantola, 2012, 2019) was adopted as the guiding tool for this purpose. Unlike the traditional Business Model Canvas, Ecocanvas incorporates circular economy principles—resource regeneration, systemic innovation, and multi-stakeholder value creation—through twelve interlinked building blocks (Daou et al., 2020).

In this study, Ecocanvas was not used to redesign complete business models, but rather to synthesize and visualize the sustainability implications of specific mitigation measures. By structuring material and energy flows, mapping potential environmental and social benefits, and identifying innovation opportunities, the tool provides a global overview of how each measure contributes to winery sustainability.

The analysis focused on two mitigation strategies implemented in the pilot winery: (i) the use of biochar in vineyards, and (ii) the reuse of irrigation water with renewable energy. The resulting ecocanvas (Figures 3 and 4) serve as integrative summaries of the interventions, offering both a systemic understanding of their impacts and a communication tool to support decision-making and scalability within the wine sector.

7.2.2 Application to Biochar-Enriched Compost

The first intervention assessed was the production and application of biochar-enriched compost, integrating vineyard pruning residues, winery by-products, and sheep manure. The methodological sequence followed the Ecocanvas stages: (i) strategic diagnosis, identifying key challenges in residue management, soil degradation, and carbon losses; (ii) stakeholder mapping and life cycle analysis, tracing material and energy flows from pyrolysis and composting through to field application; (iii) KPI definition, including compost quality improvement, methane reduction during the composting process, carbon sequestration potential, and social co-benefits such as rural employment; and (iv) strategy definition and implementation roadmap, aimed at enhancing soil resilience, closing nutrient loops, and exploring replicability in other Mediterranean wine regions. Data were sourced from technical

analyses by CEBAS-CSIC, supplemented with field visits, interviews, and participatory workshops.

7.2.3 Application to the Circular Water–Energy Model

The second intervention examined was a circular water–energy system deployed at Bosque de Matasnos, structured to ensure off-grid resource self-sufficiency. The methodology combined field data collection with Ecocanvas mapping of flows between water capture, treatment, reuse, and energy integration. Key components included: (i) a rainwater reservoir, (ii) an aquifer-fed groundwater tank, and (iii) a biological treatment facility for grey- and blackwater reuse. Energy integration was analysed through a photovoltaic microgrid with smart management, battery storage, and reduced diesel backup. Three operational scenarios were modelled, comparing baseline and hybrid configurations of aerothermal and geothermal heat pumps, with efficiency indicators such as COP/EER values, reused water volumes, and CO_2 emission reductions guiding the evaluation. Semi-structured interviews with winery managers and participatory sessions with technology partners provided qualitative insights into operational constraints, enabling factors, and stakeholder alignment.

7.3 Methodological Integration

By applying Ecocanvas to both interventions, this study integrates resource-flow mapping, KPI tracking, and stakeholder participation into a consistent analytical scheme. The methodological synthesis allows parallel evaluation of two complementary strategies—biochar-enriched compost as a soil-oriented circular solution and the water–energy nexus as an infrastructural efficiency model—within the same winery system. This integrated methodology structures the presentation of results: first the technical and agronomic outcomes; second, the social and organizational findings; and finally, the strategic and contextual interpretation of both circular models.

7.4 Results

7.4.1 Results of Biochar production, compost integration, and soil amendment application

The Ecocanvas implemented at Bosque de Matasnos demonstrates how circular logic redefines every link in the management of viticultural and forestry residues, transforming what were once by-products and livestock manure into advanced compost enriched with biochar. This is

designed to enhance the resilience, productivity, and natural capital of the vineyard. The starting point of the model is the recognised need to close local material loops and improve soil quality in response to a scenario of soil degradation, climatic pressure, and the rising cost of external inputs. While simple composting had traditionally been employed, the introduction of biochar—obtained through slow pyrolysis of local biomass, and, in recent phases, produced entirely on site—has enabled accelerated maturation, increased carbon retention, improved fertility, and, crucially, a 75% reduction in methane emissions during waste management processes.

This system thus creates circular value with both environmental and economic impacts: the resulting biochar-enriched compost contains 84% more organic carbon compared to traditional compost, reduces nitrogen volatilisation, and shortens maturation times by nearly a month, all without any detected risk of phytotoxicity. In practical terms, the vineyard gains greater input autonomy—lower expenditure on fertilisers and external waste management—while building a clearly differentiated brand image amongst consumers and distributors seeking wines with traceability, low environmental impact, and a robust sustainability narrative. This approach attracts premium market segments and strengthens visitor loyalty, with the circular experience becoming integral to the estate's enotourism narrative and digital communication strategy.

The circular value chain is closed by reincorporating the enriched compost back into the vineyard itself, valorising all secondary biomass and integrating the estate's sheep farming operations into the process. Key infrastructure and resources include designated composting areas, essential agricultural equipment, monitoring sensors, as well as trained personnel and a scientific collaboration framework with CEBAS-CSIC, which underpins rigorous monitoring and continuous optimisation at each operational stage. Organisational learning and knowledge transfer are integral to process flows, enabling improvements to be replicated and adapted across diverse regional contexts.

The social and environmental context underpins the model's viability: rising consumer awareness of ecological footprint and mounting demand for responsible agricultural practices facilitate its adoption. Simultaneously, circular production boosts rural employment and fosters a more self-sufficient and resilient local economy, reducing external dependency and strengthening territorial fabric—all set firmly within the context of the emerging European circular economy strategy and a regulatory framework that incentivises in situ valorisation of residues and certified forestry and agricultural management standards.

Stakeholder engagement is dynamic: the estate assumes operational and narrative leadership of the model, receives essential technical and scientific support from CEBAS-CSIC, and develops synergies with equipment suppliers, public institutions, and other actors linked to rural innovation and the development of niche markets. Reputational value and the enhancement of local human capital further consolidate the social sustainability of this innovation.

The cost and return components are of no less importance. The model requires initial investments in equipment and training, but the use of in-house resources, elimination of external purchases, and the potential commercialisation of compost or carbon credits consolidate economic feasibility, adding to the indirect benefits of differentiated positioning and potential access to public policy incentives.

Configured in this way, circular innovation not only produces a more efficient flow of materials, but also enables multiple social co-benefits, positions the vineyard as a benchmark in regenerative viticulture, and creates a business model capable of translating sustainability into tangible and scalable advantages. All Ecocanvas blocks thus interconnect within a virtuous circle that incorporates needs diagnosis, circular operation, robust value creation, and a systemic, integrated vision of viticultural sustainability in the Ribera del Duero.

To graphically synthesise the complexity and systemic coherence of this circular model, Figure 3 presents the Ecocanvas adapted to biomass and compost–biochar management at the Bosque de Matasnos estate. This canvas integrates resource flows, value relationships, key actors, and environmental and social returns, functioning as a visual guide prior to the analysis of each individual block

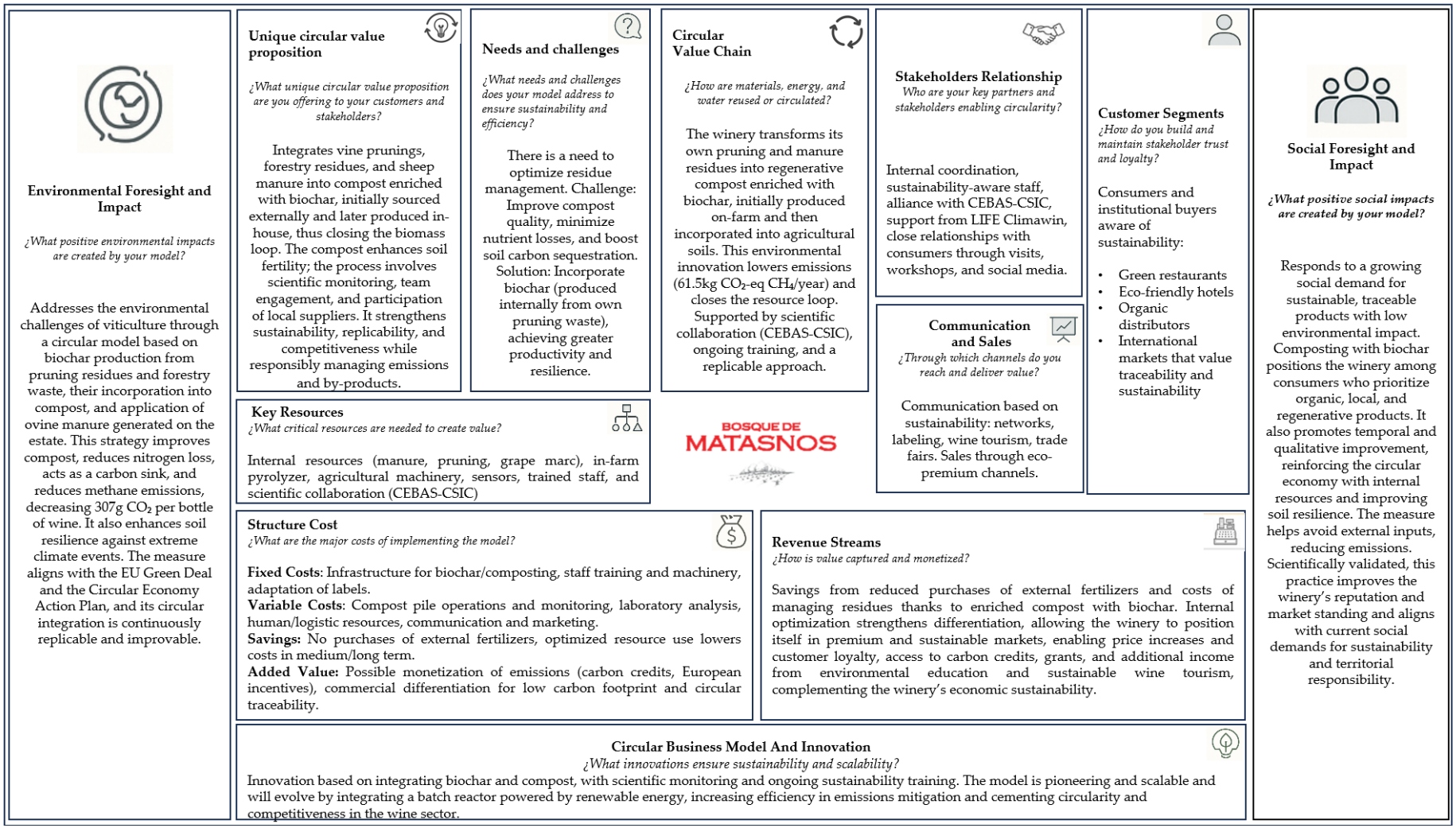


Figure 3. Ecocanvas applied to circular biomass and biochar management at Bosque de Matasnos winery within the LIFE CLIMAWIN framework

7.4.2 Results of Reuse of irrigation water as a thermal source

The implementation of the circular water–energy integration model at Bosque de Matasnos winery constitutes a technically and organisationally innovative approach to resource self-sufficiency in off-grid Mediterranean viticulture. The system is structured around three water flows: rainwater harvesting, groundwater abstraction with pre-use treatment, and biological purification of grey- and blackwater; all of which are strategically integrated with a photovoltaic-powered microgrid supported by batteries and a minimally used diesel generator. The circular synergy is achieved by deploying groundwater initially as a thermal vector in a 53 kW water-to-water heat pump for process cooling, after which the same water is sequentially diverted for vineyard irrigation—thereby closing the water loop and avoiding both wastewater discharge and freshwater over-extraction. Comparative monitoring across operational scenarios demonstrated that prioritising the water-to-water heat pump yields energy savings of up to 55.9% for cooling and 38.3% for heating compared with traditional baselines, achieving a monitored EER of 5.38 and COP of 3.95 under the optimal configuration. The annual reuse of 1,000 m^3 of water per cycle not only reduces reliance on aquifers but also strengthens drought resilience, while the off-grid energy configuration sharply decreases fossil fuel usage and associated carbon emissions.

Beyond technical gains, the model's deployment has generated multi-dimensional value: measurable improvements in energy and water efficiency, verified reductions in greenhouse gas emissions, and the creation of socio-economic co-benefits through job creation, knowledge transfer, and regional revitalisation. Stakeholder engagement—including winery staff, technology partners, local stakeholders, and research entities—has ensured participatory validation and enhanced replicability, while the application of the Ecocanvas methodology has provided a structured visual framework to integrate technical, environmental, and social dimensions of circularity into the business model. The scalability and systemic impact of this intervention are shaped by regulatory incentives, evolving sustainability certification schemes, and institutional alignment at the local and EU levels.

Summarily, the circular water–energy measure at Bosque de Matasnos showcases how integrated resource loops—operationalised under real-world off-grid constraints—can underpin climate mitigation, biodiversity stewardship, and territorial resilience, offering a transferable template for sustainable transformation in resource-constrained agri-food systems.

To graphically synthesise the complexity and systemic coherence of this circular model applied to water–energy management, Figure 4 presents the Ecocanvas adapted to the reuse of irrigation water as a thermal source at the Bosque de Matasnos estate. This visual framework integrates the flows of water and energy, the relationships of value and synergy, the main stakeholder groups, and the environmental and social returns generated by the system. The canvas functions as an overview prior to the detailed analysis of each individual block, serving as a visual reference to understand how circular resource strategies help optimize self-sufficiency, resilience, and systemic impact within the winery's operations.

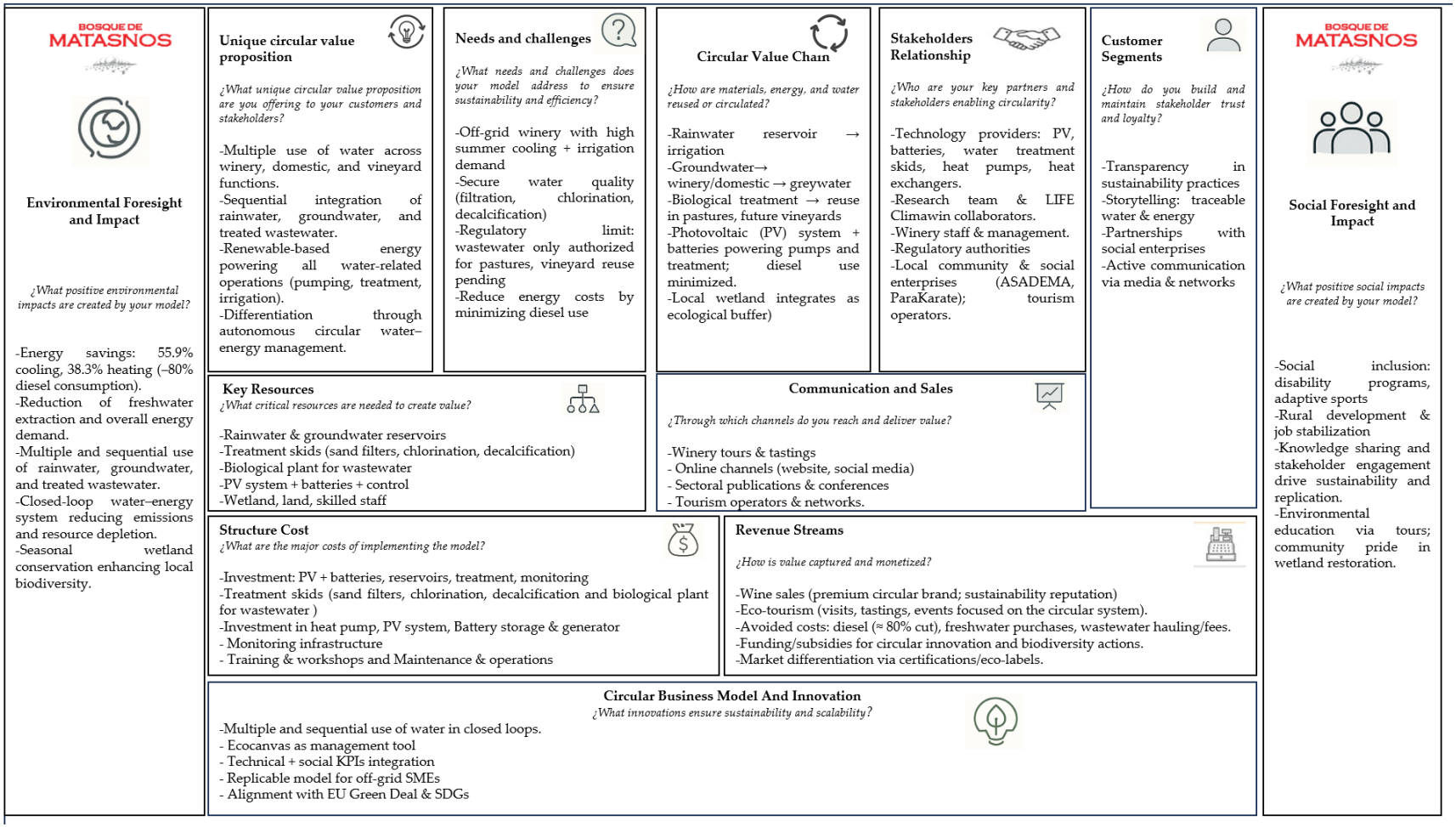


Figure 4. Ecocanvas of the Circular Water-Energy Model Implemented at Bosque de Matasnos

7.5 Conclusions from the Application of the Ecocanvas Methodology to Two Circular Economy Measures in Bosque de Matasnos

The implementation of circular composting enriched with biochar in Mediterranean viticultural systems has proven to be an agroecological strategy effective against soil degradation and climate pressure, offering clear improvements in compost quality, reductions in greenhouse gas emissions, and strengthening of resource self-sufficiency and circularity at the farm level. Beyond these technical and agronomic benefits, the application of the Ecocanvas methodology enabled a holistic structuring of relationships between productive units, key stakeholders, and flows of matter and energy, making visible the synergies and organisational co-benefits that amplify the impact of the intervention. This systemic approach strengthens the potential of the practice not only to mitigate climate change, but also to valorise waste, promote environmental identity in the final product, and provide territorial differentiation for the vineyard operation.

Meanwhile, the circular integration of water and energy in an off-grid viticulture context has demonstrated that it is possible to move beyond incremental efficiency improvements towards systemic innovation with territorial implications. The Bosque de Matasnos case illustrates how sequential water reuse—using local resources first as a thermal vector and later for irrigation—together with renewable-powered thermal systems, leads to significant energy savings and positive socio-economic and ecological impacts in rural regions exposed to demographic and climate-related pressures.

Looking ahead, both experiences demonstrate that the transition towards regenerative and resilient agri-food systems is feasible by means of local business initiatives oriented towards innovation and systemic thinking. The methodological robustness provided by Ecocanvas allows these lessons to be transferred to other agricultural sectors, as long as local context, resource availability, and integration with existing social and policy dynamics are respected.

The replicability and scalability of these circular models depend on their adaptation to the agroecological and regulatory conditions of each territory, the development of harmonised circularity indicators, and the consolidation of long-term monitoring protocols that validate and transfer positive impacts to new regions. With continued accumulation of evidence and strengthened institutional and financial support mechanisms, both circular composting with biochar and water–energy integration can serve as strategic levers for climate change

adaptation, rural regeneration, and the sustainable transformation of the Mediterranean agri-food sector.

8 CONCLUSIONS AND FINAL RECOMMENDATIONS

The Spanish wine sector, world leader in vineyard surface area and among the foremost in production and exports, faces pressing challenges from climate change and new European regulations. These demand that sustainability and resilience become central to the entire value chain. The study confirms strong environmental awareness and a growing willingness to reduce emissions, although adoption remains uneven, particularly among SMEs and cooperatives, due to financial and technological constraints.

The transition is currently driven by accessible practices such as energy efficiency (LED lighting, thermal insulation), selective waste management, reduced bottle weight, and local sourcing. These measures are widely implemented, highly replicable, and deliver immediate environmental and reputational benefits. Renewable energy deployment is also expanding, mainly through photovoltaic systems and green electricity contracts, while certification – especially SWfCP and EU organic – is gaining ground as a marker of competitiveness.

By contrast, more advanced measures – including biochar use and commercialisation, CO_2 capture and reuse, water–energy integration, fleet electrification, and wastewater reuse – remain confined to pioneering wineries with greater investment capacity. This reveals a technological and financial divide that risks deepening structural inequalities, especially since economic returns from these innovations are usually realised in the medium to long term.

A distinctive contribution of this study has been the use of the Ecocanvas methodology, which has proven effective in evaluating the feasibility of circular solutions and identifying pathways for replication. Applied to pilot cases such as Bosque de Matasnos, Ecocanvas demonstrates that circular and combined strategies – biochar-enriched compost and integrated water–energy systems – are both viable and impactful, enhancing productivity, reducing emissions, and strengthening territorial resilience. Crucially, the methodology confirms that these solutions can be replicated and scaled, provided there is institutional support and robust technical collaboration.

On this basis, several recommendations emerge. Public support should be strengthened through tailored financial instruments and training programmes to address the needs of SMEs and cooperatives. Certification schemes should be simplified and harmonised to ensure broader accessibility. Demonstration projects and regional cooperation platforms are needed to adapt innovations to diverse production scales and territories. At the same time, digitalisation should be promoted as a lever for efficiency and traceability, while incentives for packaging and logistics innovation, alongside the creation of common sustainability indicators, will be essential to track sectoral progress.

The Spanish wine sector has thus laid important groundwork for sustainability, yet structural barriers and internal heterogeneity still limit progress. Moving from isolated initiatives to a systemic, inclusive transformation will be decisive. Ensuring the replicability and scalability of advanced solutions across the sector will safeguard competitiveness, resilience, and the long-term sustainability of Spanish viticulture.

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