



REPORT

The Digital Vine: Technology and Digitalization in the Global Wine Industry – 2024 Review and Future Trajectories

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Executive Summary

The global wine industry finds itself at a critical juncture in 2024, facing a confluence of challenges including historically low production, a decline in traditional consumption, and persistent economic pressures. In this context, technological adoption and digitalization have ceased to be an option and have become an imperative necessity for survival, competitiveness, and future growth. This report analyzes the current state of digital transformation in the sector, evaluating the penetration and impact of key technologies such as Artificial Intelligence (AI), Big Data, Cloud Computing, Blockchain, Cybersecurity, E-commerce, ERP systems, Digital Marketing, and Autonomous Vehicles/Robotics.

In 2024, an increasing adoption of customized digital solutions is observed, although the overall digital maturity of the wine sector is average compared to other industries. Business management and marketing areas show the highest technological penetration, while production and viticulture, though with lower current adoption, exhibit high interest for future investment. Nevertheless, significant challenges persist, such as data management (often manual), the digital skills gap, high investment costs, and the lack of clear digital strategies, especially among small and medium-sized enterprises (SMEs), creating a digital divide within the industry.

Technologies like AI and Big Data are beginning to unlock efficiencies in precision viticulture, winemaking optimization, and marketing personalization, although their tangible impact in the vineyard is still developing for many users. Cloud Computing stands as a key enabler, democratizing access to sophisticated software. Blockchain offers promise for traceability and combating counterfeiting, especially in the premium wine segment. E-commerce and direct-to-consumer (D2C) channels have proven vital, driven by the need for greater brand control and direct customer relationships. ERP systems are consolidating as the digital backbone for comprehensive management. Robotics and autonomous vehicles are advancing to mitigate labor shortages and improve precision in the field and winery.

Future projections indicate robust growth for technologies applied to wine, but success will depend on the sector's ability to close the skills gap, foster a culture of innovation, and develop cohesive digital strategies. Industry collaboration and support from organizations like the International Organisation of Vine and Wine (OIV) will be crucial for navigating the transition to a more digitalized, sustainable, and resilient future. This report provides a comparative analysis of technology adoption in ten major producing countries, highlighting their strengths, weaknesses, and specific

initiatives, and concludes with strategic recommendations for industry players.

I. The Global Wine Market in 2024: A Challenging Landscape Driving Innovation

The year 2024 has presented a complex scenario for the global wine industry. A series of interconnected factors, from extreme weather conditions to shifts in consumption patterns and economic pressures, have shaped an environment that, while challenging, also acts as a catalyst for the adoption of technological and digital innovations.

A. Overview of Global Vitiviniculture (2024 Data)

The latest figures from the International Organisation of Vine and Wine (OIV) and other official sources paint a picture of contraction and volatility in the sector's main indicators.¹

- **Vineyard Surface Area:** The global vineyard surface area continued its downward trend in 2024, contracting by 0.6% to reach 7.1 million hectares. This is the fourth consecutive year of decline, primarily driven by vineyard grubbing-up in major producing regions in both hemispheres.¹ This reduction affects all grapes, but especially those intended for winemaking.
- **Wine Production:** Global wine production (excluding juices and musts) in 2024 is estimated at a historic low of 225.8 million hectoliters (Mhl), representing a 4.8% drop compared to the already low level of 2023. This figure is the lowest recorded in over 60 years, since 1961.¹ Extreme weather conditions, such as early frosts, torrential rains, and prolonged droughts, along with the consequent pressure from diseases, have severely impacted vineyard productivity globally.²
- **Wine Consumption:** Global wine consumption in 2024 is estimated at 214.2 Mhl, a decrease of 3.3% compared to 2023, also placing it at the lowest level since 1961.¹ This decline is attributed to decreasing demand in major markets, exacerbated by high average prices due to low production volumes and the persistent effects of past inflation.¹
- **International Trade:** International wine trade in 2024 was affected by low production volumes and high average export prices. Although the total export volume remained relatively low at 99.8 Mhl (matching 2023 but 5% below the five-year average), this was offset by a strong export value, which reached 35.9 billion euros. The average export price remained stable at 3.60 euros per liter, matching the 2023 record.¹

Table 1: Key Figures of the Global Wine Sector 2024 vs. 2023 and 5-Year

Average

Indicator	2024 (Estimated/Preliminary)	Variation vs. 2023	Variation vs. 5-Year Average	Main Sources
Vineyard Surface Area (Mha)	7.1	-0.6%	ND	1
Wine Production (Mhl)	225.8	-4.8%	ND	1
Wine Consumption (Mhl)	214.2	-3.3%	ND	1
Export Volume (Mhl)	99.8	0.0%	-5.0%	1
Export Value (billion €)	35.9	-0.3%	ND	1
Average Export Price (€/L)	3.60	0.0%	+29.6% (vs pre-pandemic)	1

Note: Mha = Million hectares; Mhl = Million hectoliters; billion € = Billions of euros; ND = Not Directly Available in the extracts for the 5-year average in all cases, but inferred from discussions. The 2024 figures are provisional or preliminary according to the OIV.

B. Key Market Dynamics and Challenges

The wine industry faces a series of complex dynamics and interrelated challenges that are reshaping its landscape.

- Impacts of Climate Change:** Extreme weather events are becoming more frequent and intense. Heatwaves in Europe have advanced harvests and altered grape composition, while droughts in Australia and California have stressed vines and reduced yields.⁶ Frosts, floods, and hailstorms have also contributed to production volatility.² This climatic variability not only affects the quantity but also

the quality and typicity of wines, driving the need for adaptation strategies and resilient technologies.³

- **Changes in Consumer Preferences:**

- **Premiumization:** A sustained trend towards the consumption of higher-priced wines is observed, particularly in the \$12 to \$15 or higher range, while sales of table wines under \$10 continue to decline.⁶ This demands a refocusing of producers towards higher value-added segments.
- **Health Consciousness and Moderation:** The "sober curious" movement and greater health awareness are driving demand for low-alcohol or no-alcohol (NoLo) wines, especially among younger generations.⁶ The World Health Organization (WHO) has contributed to this shift in perception with messages about alcohol consumption.⁷
- **Sustainability and Ethics:** Consumers, particularly younger ones, increasingly prioritize brands with ecological and sustainable practices. This includes demand for organic and biodynamic wines, as well as environmentally friendly packaging.⁶ Sustainability is becoming a decisive purchasing factor.
- **Generational Gap:** While the Baby Boomer generation, loyal and consistent consumers, reduces its consumption due to age, younger generations (Millennials and Gen Z) are not adopting wine at the same rate as previous generations.¹⁰ Connecting with this younger, more diverse audience requires new approaches and products.

- **Economic Pressures:** Global inflation has affected consumers' discretionary spending, making products like wine less of a priority for some.⁷ Simultaneously, production costs for wineries (energy, raw materials, labor, transport) have increased, putting pressure on profitability.⁷

- **Inventory Issues:** Following the pandemic, there was an accumulation of inventory in the supply chain (wholesalers and retailers) due to disruptions and speculative purchasing ("pantry-loading").¹⁰ In 2023 and 2024, these actors have been reducing their inventory levels (from about 65 days during the pandemic to as low as 15 days in some cases in the US) to manage the higher costs of holding inventory due to rising interest rates. This has caused a temporary decrease in demand for producers.¹⁰

The confluence of historically low production (a supply shock due to climate), a decline in traditional consumption (a demand shock), and economic inflation creates a "perfect storm" scenario that makes traditional business models increasingly unsustainable. Wineries are pressured from both the supply side (lower production capacity or variable quality) and the demand side (fewer traditional buyers, greater

price sensitivity).

Furthermore, the reduction of inventories held by wholesalers and retailers ¹⁰, coupled with the rise of e-commerce ²², is compressing the traditional three-tier system in some markets. This forces producers to interact more directly with consumers, thereby accelerating the need for D2C technologies and strategies.

Finally, although consumer demand for sustainability is increasing ⁶, achieving it profitably in a challenging climate requires technological intervention (precision agriculture, resource management). This turns a consumer trend into a driver of technological adoption, where technology becomes the bridge between consumer demand for sustainability and the ability to deliver it under difficult conditions.

C. The Imperative of Digital Transformation

The combined market pressures – climate change, evolving consumers, economic difficulties, and intensified competition – create an urgent need for wineries to adopt technology. Digitalization is no longer an option but a strategic imperative to improve operational efficiency, build resilience against volatility, expand market reach, and foster deeper engagement with consumers.¹⁹ The ability to adapt quickly to these new realities will largely depend on the intelligent integration of digital solutions throughout the entire wine value chain.

II. Current State of Digitalization in the Wine Industry

The global wine industry is undergoing a digital transition, albeit at a pace and depth that varies considerably between regions and types of companies. While the potential of technology is increasingly recognized, the overall digital maturity of the sector still presents significant opportunities for growth.

A. General Digital Maturity and Adoption Trends

The wine sector is progressively adopting customized digital solutions, but its overall digital maturity is considered average compared to other industries like coffee or oil.²⁴ This situation indicates high growth potential and the possibility of disruption through innovation.

Business management solutions (such as ERP systems for finance and accounting) and marketing tools are the most widespread. More than 75% of wine producers and commercial wine businesses use digital solutions for financial management, and more

than half employ CRM systems for direct-to-consumer (D2C) sales.²⁴ Around 50% use digital data management for marketing.²⁴

In contrast, the adoption of digital tools is lower in the areas of wine production (approximately 40% of producers) and vineyard management, although the latter show the greatest interest for future investments.²⁴ This suggests a recognition of the need, but perhaps also greater barriers to entry or longer investment cycles for production technologies.

Figure 1: Adoption Rates of Digital Solutions in the Wine Supply Chain Stages (2024)

(Note: This chart is a conceptual representation based on ProWein data.²⁴ Exact percentages may vary and are presented as indicative ranges.)

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section Vineyard Management
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GPS for Planting :crit, active, 2024-01-01, 60d
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Precision Tools :active, 2024-01-01, 45d
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IoT Sensors (Low Adop.) :2024-01-01, 30d
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section Wine Production
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Production Software :active, 2024-01-01, 50d
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Digital Berry Selection :2024-01-01, 35d
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AI in Fermentation (Low) :2024-01-01, 25d
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section Marketing and Sales
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Email Marketing :crit, active, 2024-01-01, 85d
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Social Media :crit, active, 2024-01-01, 80d
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Own Online Store :active, 2024-01-01, 70d
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CRM for D2C :active, 2024-01-01, 65d
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E-commerce (General) :active, 2024-01-01, 75d

section Business Management

ERP (Finance/Acct.) :crit, active, 2024-01-01, 90d

Data Management (Manual) :active, 2024-01-01, 65d

%% Conceptual Adoption Legend (Not part of Mermaid chart, but explanatory)

%% Very High Adoption (>75%) : ERP (Finance/Acct.)

%% High Adoption (60-75%) : Email Marketing, Social Media, Own Online Store, CRM for D2C

%% Medium Adoption (40-60%) : Production Software, GPS for Planting, Precision Tools

%% Low Adoption (<40%) : Digital Berry Selection, IoT Sensors, AI in Fermentation

Source: Interpretation of data from ProWein Business Report Special Report Digitalisation.²⁴ Bar lengths are illustrative of adoption levels.

B. Key Areas of Digital Focus

Digitalization is concentrating on several functional areas within wine companies:

- **Business Management:** ERP systems are fundamental for finance, accounting, and overall operational supervision. More than three-quarters of wine sector companies use ERP systems for financial and accounting management.²⁴
- **Marketing and Sales:** CRM systems are used by more than half of companies to improve direct-to-consumer (D2C) sales. Email marketing and social media are employed by more than two-thirds of companies. Approximately two-thirds operate their own online stores, and more than a quarter sell through online platforms or retailers.²⁴ Despite the digital boom, multimodal marketing remains important, with half of companies still using paper mailings and 39% continuing with telephone marketing.²⁴
- **Production:** Around 40% of wine producers use digital tools in wine production, such as digital berry selection machines used during harvest.²⁴
- **Vineyard Management:** Although with slightly lower current adoption than production, technologies such as GPS for vineyard planting (a process that may occur once every thirty years) and specific digital tools for precision agriculture in tasks like spraying, pruning, and fertilization are used.²⁴

C. Challenges in Digital Adoption

Despite the potential, the industry faces several obstacles to deeper and more

widespread digitalization:

- **Data Management:** This is a persistent challenge due to limited resources for data collection, management, and cleaning. Nearly two-thirds of wine companies still manually enter data into spreadsheet programs like Excel, underscoring the need for better data integration and automation.²⁴ Only one in four companies has dedicated internal staff for this task.²⁴ This situation creates a "data-action gap": although some data is collected, especially in business and marketing areas, widespread manual entry and lack of dedicated data personnel suggest a significant disconnect between data collection and its effective use for strategic decision-making. Even when tools exist, their full potential is not realized if the underlying data is difficult to aggregate and analyze.
- **Skills Gaps and Digital Literacy:** 72% of experts recognize the need for continuous learning and investment in digital skills.²⁴ Limited digital literacy is a constraint for broader adoption of agritech in general.²⁷
- **Investment Costs:** The high initial investment required for hardware, software, and implementation can be a significant barrier, especially for SMEs.²⁵
- **Lack of Clear Digital Strategy:** A clear strategy and defined processes are crucial for successful digitalization but are often lacking, hindering the effective implementation of technologies.²⁴ Experts emphasize that having a clear strategy is more fundamental than simply implementing tools.²⁴
- **Resistance to Change:** Tradition holds considerable weight in the wine industry, and some viticulturists and winemakers may be reluctant to adopt new technologies, preferring established methods.²⁹

The lower current adoption in production and viticulture technology, despite high *interest* in future investment in these areas ²⁴, points to a possible confluence of a perception of higher risk, longer return on investment horizons, or greater operational disruption for these core activities compared to more administrative or customer-facing technology. This could be interpreted as an investment paradox: the need is recognized, but barriers (cost, complexity, perceived risk of altering essential production processes) may be delaying actual investment compared to, for example, implementing a new marketing tool.

Finally, despite the high use of basic digital marketing tools (email, social media), the low planned investment in *new* digital marketing solutions (only 15% for 2025 ²⁴) suggests an underestimation of advanced capabilities like personalization and data-driven marketing, or perhaps saturation with basic tools without a strategy for more advanced ones. This indicates a possible underutilization of digital marketing's

potential to drive significant growth.

III. In-Depth Analysis: Key Technologies Reshaping the Wine Value Chain (Status 2024)

Digital transformation in the wine industry is being driven by a diverse set of technologies, each with specific applications and varying impact across the value chain, from the vineyard to the consumer.

A. Artificial Intelligence (AI) and Big Data Analytics

- **Relevance:** AI and Big Data are fundamental for converting large volumes of agricultural, production, market, and consumer data into actionable information. This allows for greater precision, efficiency, and personalization throughout the wine industry.
- **Applications and Adoption (2024):**
 - **Precision Viticulture:** AI analyzes data from sensors, drones (15% adoption in US vineyards³⁰), and satellites for yield prediction (an 8% accuracy improvement is possible³¹), disease and pest monitoring, and optimization of irrigation and fertilization.⁶ Adoption in the US is still low for AI sensors (9%) and robots (3%) in vineyards.³⁰
 - **Winemaking:** AI improves quality control and optimizes fermentation. Notable examples include Palmaz Vineyards' FILCS system³² and E. & J. Gallo's real-time fermentation monitoring.³⁴ It is also used to analyze wine components (7% adoption in US wineries³⁰) and assist in blending.⁶ Optical sorters with AI have 9% adoption in US wineries.³⁰
 - **Consumer Insights and Personalization:** AI analyzes wine reviews (sentiment analysis²⁶) and purchasing behavior to offer personalized recommendations. Total Wine uses these techniques to segment over 7.5 million customers.²⁶ AI-based virtual sommeliers have 4% adoption in the US.³⁰
 - **Marketing and Sales:** Tools like ChatGPT are used for creating marketing content (39% adoption in the US), office applications (30%), image generation (20%), content analysis (13%), and social media management (12%).²⁶
- **Impact and ROI:**
 - **Vineyard:** In the US, 34% of users report increased operational efficiency, but 76% indicate little to no cost savings, and 74% little to no improvement in grape quality.³⁰ A case in Cyprus showed an 8% increase in perceived wine quality with smart farming.³⁸
 - **Winery:** 48% of US users report improved operational efficiency, 35% cost

savings, and a surprising 49% an increase in wine quality due to AI data.³⁰ A case in Italy reported a 5.3% improvement in intrinsic product quality with smart farming.³⁸

- **Marketing/Sales:** 35% of US users identify increased operational efficiency, 21% cost savings, and 43% an increase in service, sales, or marketing quality.³⁰
- **AI for Customer Interaction:** 42% of US users report improved customer service quality, 34% improved operational efficiency, and 28% cost savings.³⁰
- **Case Studies/Examples:** Palmaz Vineyards (FILCS for fermentation ³²), E. & J. Gallo (fermentation monitoring ³⁴), Concha y Toro (Harvest 5.0 for predictive models ²⁰), The Yield/Yamaha Agriculture Australia (yield prediction ³¹), VineView (aerial image analysis ³⁴), Deep Sky Vineyard (Google Cloud for agricultural data analysis, with a 75% reduction in human errors and a 50% increase in efficiency ³⁹), Total Wine (personalized recommendations ²⁶). The company bw166 specializes in data analytics for alcoholic beverages.¹⁰
- **Benefits:** Improved decision-making, resource optimization, quality improvement, cost savings in some areas, personalized customer experiences.
- **Challenges:** High initial investment, data quality and integration, need for specialized skills, "black box" nature of some AI, AI energy consumption.²⁶ The industry underestimates AI's potential for content creation and personalization.²⁴

A deeper analysis of AI adoption reveals a marked trend: current adoption rates in the US ³⁰ are significantly higher for AI tools in marketing, sales, and administration (almost 40% for ChatGPT) than for operations in vineyards (<15%) or wineries (<10% for most). This suggests that companies are first applying AI in lower-risk areas with more easily quantifiable ROI, such as marketing content generation, before tackling complex, capital-intensive production processes. The ease of access and implementation of tools like ChatGPT, with immediately visible results (e.g., a blog post), contrasts with AI for vineyards or wineries (e.g., robotic harvesters, AI-driven fermentation), which requires significant hardware, integration, and process changes, with a potentially longer-term and less immediately obvious ROI.

Furthermore, there is an apparent disconnect between AI's potential and its perceived impact on viticulture. Although AI promises significant improvements in the vineyard (yield, quality, efficiency ⁶), a large percentage of current US users report little to no impact on cost savings or grape quality.³⁰ This could indicate that the technology is in an early stage, incorrect implementation, unrealistic expectations, or that the benefits are long-term and have not yet fully materialized. The discrepancy between the 8% improvement in yield prediction accuracy in research ³¹ and user reports ³⁰ suggests

that current commercial applications may not be as advanced as research tools, that users lack the expertise to fully leverage them, or that the definition of "impact" varies.

Finally, the effectiveness of AI, particularly in precision viticulture and consumer personalization, heavily depends on large, high-quality datasets. The prevalent manual data entry and lack of resources for data management²⁴ act as a fundamental bottleneck, limiting the potential of more sophisticated AI applications. AI algorithms³² require data to learn and make predictions. If data is manually entered, prone to errors, siloed in spreadsheets, and not standardized, the AI's input is compromised, leading to suboptimal results.

B. Cloud Computing

- **Relevance:** Cloud Computing provides a scalable, flexible, and often more cost-effective infrastructure for data storage and processing, as well as software delivery. It is crucial for handling the increasing volumes of data from IoT, AI, and ERP systems.
- **Applications and Adoption (2024):**
 - **Data Management and Analytics:** Storage and processing of vineyard and winery data, enabling advanced analytics.³⁹ Deep Sky Vineyard uses Google Cloud for agricultural data analysis.³⁹
 - **Winery Management Software:** Hosting cloud-based ERPs and specialized winery software (e.g., vintrace, InnoVint, Crafted ERP on NetSuite).³⁸ Chandon reported annual savings of \$75,000 with InnoVint.³⁸
 - **Collaboration and Accessibility:** Enables real-time data access and collaboration for teams in different locations.⁴⁴
- **Benefits:** Scalability, cost efficiency (pay-per-use, reduced capital expenditure on hardware), reliability, accessibility, disaster recovery, access to advanced technologies (AI/ML services offered by cloud providers).⁴⁰ Union Wine Co. uses vintrace to facilitate cellar staff work, real-time updates, better harvest scheduling, and time for R&D.⁴⁴ Wine Access migrated to AWS to overcome outdated technology, improve regulatory compliance, optimize reporting, and secure inventory.⁴⁸
- **Main Providers and Market Share (General Cloud Market):** AWS (31%), Microsoft Azure (20%), Google Cloud Platform (GCP) (11%).⁴⁹ These platforms offer a range of services applicable to wineries, including IaaS, PaaS, SaaS, AI/ML tools, and IoT platforms. Azure stands out for hybrid cloud and integration with Microsoft products; GCP for AI/analytics affordability.⁴¹
- **Challenges:** Managing multicloud environments, cost optimization (wasted cloud

spend can be 32%⁴⁰), security and compliance concerns (though providers offer robust solutions⁴⁹), vendor lock-in, need for FinOps practices.⁴⁰

Cloud adoption is especially crucial for SMEs in the wine industry. The scalable and pay-as-you-go models of Cloud Computing⁴⁰ lower the barrier to entry for adopting sophisticated software (ERP, specialized winery management) that was previously only within reach of large companies. This can help bridge the digital divide, as SMEs face investment cost challenges²⁵, and cloud solutions (SaaS like InnoVint³⁸ or vintrace⁴⁴) decrease initial hardware and maintenance expenses.

Furthermore, the ability of cloud platforms to centralize and manage large datasets⁴⁰ is a fundamental step before wineries can effectively leverage AI and Big Data analytics. Without a unified cloud data strategy, data remains siloed, and AI initiatives will struggle. AI needs data; if it is scattered across on-premise systems or spreadsheets²⁴, it is difficult for AI to access and analyze it. Cloud platforms³⁹ provide the means to consolidate this data, creating the necessary "data lake" or "data warehouse."

The emergence of "cloud-native" wineries is also anticipated. New wineries or those undergoing significant transformation may opt for a "cloud-native" approach from the outset, building their entire IT infrastructure and applications in the cloud. This offers maximum agility and scalability but requires careful planning regarding vendor selection and data governance. Existing companies like Wine Access are already migrating entirely to AWS⁴⁸, and it is logical to infer that new companies, without the burden of legacy systems, would consider starting directly in the cloud for benefits like scalability and reduced capital expenditure from day one.

C. Blockchain Technology

- **Relevance:** Blockchain offers a decentralized, immutable, and transparent ledger, promising solutions for traceability, authenticity, anti-counterfeiting, and enhancing trust in the wine supply chain.
- **Applications and Adoption (2024):**
 - **Traceability and Provenance:** Tracking wine "from grape to glass," verifying geographical origin and production methods.¹⁹ The OIV has shown interest in this area.⁵³
 - **Anti-Counterfeiting and Fraud:** Ensuring the authenticity of premium wines, combating illicit trade and incorrect labeling.²⁵
 - **Supply Chain Transparency and Efficiency:** Improving information exchange and trust among actors (farmers, wineries, distributors, consumers).⁵¹ Smart contracts can automate transactions.⁵¹

- **Sustainability Certification:** Potentially, it can serve as a tool for sustainability management and certification.⁵²
- **Current Adoption and Platforms:** Adoption is still emerging, with low commercial deployment.⁵³ There is more research and pilot projects than widespread use.
 - Examples: TRACEWINDU project (led by UAB, uses smart labels and blockchain for traceability, correlating sensory analyses to generate a product passport via QR code⁵²). A study proposed a system based on Hyperledger Fabric for wine trade between wineries.⁵¹ Farmonaut mentions blockchain-based traceability solutions.¹⁹ South Africa Wine's R&D&I strategy includes developing a blockchain ecosystem for South African wine.⁹
- **Benefits:** Increased transparency, security, immutability, trust, authenticity, potential for automated processes via smart contracts.⁵¹
- **Challenges:** Significant implementation costs, consumer privacy concerns, limited knowledge and adoption by stakeholders, scalability, interoperability between different blockchain systems, complexity of integration with existing systems.⁵³

The "trust premium" offered by Blockchain is particularly relevant for high-value, export-oriented wine segments. The main benefits of this technology (anti-counterfeiting, provenance assurance) are more valuable for premium wines, where trust and authenticity justify a higher price and fraud risks are greater.²⁵ For bulk or low-cost local wines, the cost-benefit ratio may not yet be favorable, given Blockchain's implementation cost.⁵³

Consumer adoption is key to Blockchain's success in wine. Although the technology can ensure supply chain integrity, its value is only fully realized if consumers understand, trust, and use the information it provides (e.g., via QR codes on labels, as in the TRACEWINDU project⁵²). This requires consumer education and user-friendly interfaces. If consumers do not scan the QR code or do not understand/value the Blockchain-verified data, the system's impact on purchasing decisions is lost.

Permissioned blockchains are likely to dominate in B2B wine trade. Given the private nature of commercial data and existing relationships within the supply chain, private or permissioned blockchains (like Hyperledger Fabric, mentioned in⁵¹) are more suitable for B2B wine trade and data exchange between known actors (wineries, distributors, supervisors) than public, permissionless blockchains. This is because the managed information is private, and participants do not wish to share it publicly as it affects their businesses.⁵¹

D. Cybersecurity

- **Relevance:** Increasing digitalization across the wine value chain (production, inventory, sales, D2C) expands the attack surface, making robust cybersecurity essential to protect sensitive data, operational continuity, and brand reputation.
- **Key Threats:**
 - **Ransomware:** Main cause of losses, targeting both primary organizations and their suppliers.⁵⁸
 - **Phishing:** Deceiving employees into revealing sensitive information, leading to data breaches.⁵⁸ Although decreasing as a primary point of failure, it remains a threat.
 - **Third-Party/Supplier Risks:** A dominant driver of cyber claims (31% of claims, 23% of material claims in one report⁵⁸). Compromise of connected systems and external providers (e.g., IT providers, software vendors).
 - **Data Breaches:** Theft of customer data (credit card information, PII), employee data, proprietary business information.⁶²
 - **Attacks on Industrial Control Systems (ICS)/Operational Technology (OT):** Particularly relevant for larger wineries with automated production. Outdated software, weak passwords, and default credentials are key vulnerabilities.⁶⁰
- **Impact of Incidents:** Financial losses (e.g., MGM Resorts \$100M, Caesars \$15M ransom⁶²; Crimson Wine Group affected 26,238 individuals⁶³), operational disruption (e.g., inability to accept/ship orders), reputational damage, loss of customer trust, regulatory penalties. The global cost of cybercrime is expected to reach \$10.5 trillion by 2025.⁵⁹
- **Preparedness and Best Practices:**
 - Comprehensive cybersecurity plan, regular IT/risk assessments.⁶¹
 - Strict access controls, multi-factor authentication (MFA).⁵⁸
 - Regular software updates and patch management.⁶¹
 - Employee training in threat recognition.⁵⁸
 - Data protection and regular, verified backups.⁶¹
 - Incident response plan.⁵⁸
 - Network segmentation (IT/OT separation).⁶⁴
 - Real-time monitoring and threat detection.⁶⁴
 - Secure POS systems.⁶⁶
 - Cyber insurance.⁵⁸
 - Third-party risk management (vendor assessments).⁵⁸
- **Recent Incidents:** Crimson Wine Group data breach (June 2024, financial and payment card details potentially exposed for 26,238 individuals⁶³). General

increase in attacks on the Food and Agriculture sector.⁶⁰ Sunsweet Growers Inc. data breach (December 2024⁶⁷). The interconnectedness of the wine industry amplifies risk. The growing reliance on a complex network of third-party providers (software vendors, marketing agencies, logistics partners) significantly expands their collective vulnerability.⁵⁸ A breach in one supplier can cascade to multiple wineries, making vendor security assessments critical.

Operational Technology (OT) cybersecurity is a latent threat for modernizing wineries. As they adopt more automation and IoT in production²⁵, OT security becomes a critical, though potentially overlooked, concern. These systems often have different security protocols and longer lifecycles than IT systems.⁶⁴ An attack on these systems could halt production or alter recipes, a different type of damage than a customer data breach.

SMEs are disproportionately vulnerable. Smaller wineries, while digitalizing, often lack the dedicated IT/security staff and resources of larger companies²⁵, making them easier targets for cybercriminals using widespread tactics like phishing or exploiting common software vulnerabilities.

E. E-commerce and Direct-to-Consumer (D2C) Channels

- **Relevance:** E-commerce and D2C sales are increasingly vital for wineries, offering higher margins, direct customer relationships, and brand control, especially when traditional channels face disruptions.
- **Market Growth and Trends (2024):**
 - The wine e-commerce market is projected to grow by USD 13.00 billion during 2024-2029, at a CAGR of 7.8%.²² Another source estimates a CAGR of 8.8% for 2024-2030.²³
 - Drivers: Growing preference for online shopping, convenience, wider selection, personalized recommendations, home delivery.²²
 - D2C is a major sales source for smaller wineries.¹⁰
 - Online wine sales are expected to account for over 20% of global wine sales by 2030.⁶⁹
 - Online wine sales in the US are decreasing as a percentage of total sales in 2025 after the pandemic boom but remain important.¹²
- **Technologies:**
 - E-commerce platforms (e.g., WineDirect⁴⁵).
 - CRM systems to manage customer data and interactions.¹⁵
 - AI for personalized recommendations and virtual sommeliers.¹⁵
 - Digital marketing tools to drive traffic (SEO, social media, email).⁴²

- Online payment applications.²²
- **Benefits:** Higher profit margins, direct customer engagement and loyalty building, brand control, access to valuable customer data, market diversification.¹⁰
- **Challenges:** Complex shipping regulations between states/countries, customer acquisition cost, competition, need for robust logistics and compliance, managing online customer service, risk of underage purchases.²²

D2C success hinges on data-driven personalization. With increasing online competition, wineries that can effectively leverage customer data (purchase history, preferences from CRM/AI systems ¹⁵) to offer personalized experiences, recommendations, and targeted promotions will gain a significant competitive advantage. In a saturated online market ²², generic offers get lost; personalization creates relevance and loyalty.

The "experience economy" extends to the online realm. Successful D2C is not just transactional; it's about extending the winery experience to the digital environment. This includes virtual tastings ⁶, immersive storytelling via QR codes ³⁶, and exclusive online content, bridging the gap between physical visits and online purchases. This caters to consumers who value experiences ¹² and helps build a brand connection beyond simply selling a bottle.

Regulatory complexity remains a key bottleneck for D2C expansion. Despite technological enablers, fragmented and often restrictive regulations governing alcohol sales and shipping (implicitly mentioned by Wine Access's challenges in ⁴⁸) remain a significant hurdle for wineries looking to scale their D2C operations, particularly across state or international borders.

F. Enterprise Resource Planning (ERP) Systems

- **Relevance:** ERP systems integrate all facets of a winery's operations—from vineyard management and production to inventory, sales, finance, and regulatory compliance—into a single, unified platform, enabling streamlined processes and data-driven decision-making.
- **Adoption and Key Systems (2024):**
 - More than 75% of wine companies use digital solutions like ERP for finance and accounting.²⁴
 - Popular systems tailored for wineries: Crafted ERP (built on NetSuite ⁴²), vintrace ⁴⁴, InnoVint ³⁸, Sage X3/300 ⁷¹, WineDirect (D2C focused but integrates ³⁸), Process2Wine, EzyWine, Orion Wine Software.³⁸
 - General ERPs like SAP and Microsoft Dynamics are also used, but specialized solutions are gaining ground.

- **Benefits:**
 - **Operational Efficiency:** Streamlined workflows, automation of routine tasks, reduction of manual data entry.⁴² A Peruvian winery achieved a 20% reduction in operational costs.⁷⁵
 - **Cost Savings:** Better resource allocation, inventory control (reduced spoilage/stockouts), purchasing optimization.⁴²
 - **Improved Inventory Management:** Real-time tracking from grape to bottle, lot traceability, monitoring of the aging process.⁴⁷
 - **Enhanced Compliance and Traceability:** TTB compliance, tax/excise documentation, backward and forward traceability.²⁵
 - **Data-Driven Decision-Making:** Real-time data, analytics, and reporting for better planning and forecasting.⁴²
 - **Scalability:** Cloud-based ERPs can scale with winery growth.⁴³
 - **Improved Financial and Cost Management:** Accurate cost of goods sold (COGS) for each bottle.⁴²
- **Case Studies:** Crafted ERP enables accurate per-bottle costing.⁴² Chandon achieved annual savings of \$75,000 with InnoVint's paperless workflow.³⁸ A Peruvian winery using an ERP for retailers experienced a 20% reduction in operational costs and a 15% increase in customer satisfaction.⁷⁵
- **Challenges:** High implementation costs, complexity of implementation, need for customization, data migration, employee training and adoption, potential for underestimating staffing or project scope.⁷³

An ERP acts as the "digital backbone" for holistic management. True operational excellence and data-driven decision-making in a winery require an ERP as the central nervous system. Without it, other technologies (AI, IoT, e-commerce) operate in silos, limiting their overall impact.⁴² An ERP⁴³ connects these functions, allowing, for example, sales data to inform production planning, or production costs to accurately feed financial reports.

Cloud-based ERPs are democratizing access for SMEs. The shift towards cloud ERP solutions (e.g., Crafted ERP on NetSuite⁴²) is making comprehensive management tools more accessible and affordable for small and medium-sized wineries, which constitute the bulk of the industry.⁷¹ Traditional on-premise ERPs had high upfront hardware and licensing costs, whereas cloud ERPs⁴³ typically use a subscription model, reducing initial capital investment and offering scalability.

Successful ERP implementation is a business transformation, not just a technology project. The high impact of institutional leadership support (77% critical success factor⁷²) and effective communication (60% top skill needed⁷²) for ERP success

underscores that implementation is less about the software itself and more about organizational change management, process re-engineering, and strategic alignment.

G. Digital Marketing and Consumer Engagement

- **Relevance:** In a competitive market with changing consumer preferences, effective digital marketing is crucial for brand building, customer acquisition, and fostering loyalty, especially for D2C sales.
- **Strategies and Technologies (2024):**
 - **Content Marketing and Storytelling:** Sharing winery narratives, history, sustainability efforts.³⁶ Podcasting.³⁶
 - **Social Media Marketing:** Instagram (Reels, Stories, Live), TikTok to attract younger audiences (Gen Z, Millennials); community building.²⁴ Using social media data to improve campaigns.⁷⁰
 - **SEO and SEM:** Driving online visibility and traffic to e-commerce sites.²⁴
 - **Email Marketing:** Regular communication, promotions, wine club announcements.¹⁰
 - **Influencer Marketing:** Collaborating with micro-influencers for authentic storytelling.⁴²
 - **Personalization:** Using CRM and AI data for targeted offers, recommendations.¹⁵ AI for writing captions, creating content.⁷⁰
 - **Immersive and Interactive Experiences:**
 - QR Codes on Labels ("Living Labels"): Linking to vineyard stories, winemaker information, AR experiences.²⁵
 - Virtual Winery Tours and Tastings: Gaining popularity, especially post-pandemic.⁶
 - AI-Powered Virtual Sommeliers: Personalized pairing suggestions, enhancing at-home experiences.³²
 - Augmented Reality (AR): Enhancing winery visits, label interactions.⁶
- **Case Study:** Frescobaldi's partnership with Vivino: improved digital presence, 22 million interactions, average rating >4 stars, content in 10 languages, leveraging Vivino's AI and user reviews.⁷⁶
- **Benefits:** Increased brand awareness, greater reach (especially to younger demographics), direct consumer engagement, data collection for better segmentation, driving D2C sales.
- **Challenges:** Keeping up with rapidly evolving digital trends, content creation demands, measuring ROI, data privacy concerns, standing out in a saturated digital space. Only 15% of wine companies plan to invest in *new* digital marketing solutions by 2025, suggesting an underestimation of advanced tools.²⁴

Authenticity and storytelling prevail over generic marketing. Consumers, especially younger ones, seek authentic connections and stories behind the wine.³⁶ Digital channels provide the perfect platform for wineries to share their unique narratives, sustainability efforts, and the people behind the brand, going beyond simple product features. Wineries need to "talk beyond the wine" because many claim similar benefits (family-owned, organic, etc.).⁶⁸

There is a convergence of physical and digital experiences. The most innovative marketing strategies are blurring the lines between physical and digital. QR codes on bottles³⁶, AR-enhanced tasting rooms⁶, and virtual extensions of physical visits¹⁵ create a seamless and engaging customer journey. "Living labels"³⁶ connect a physical product with digital content, while virtual tastings⁶ bring a traditionally physical experience to the online environment.

Micro-influencers offer targeted reach for niche wineries. For smaller or niche wineries, collaborating with micro-influencers⁴² can be more effective and cost-efficient than mass marketing, allowing them to reach specific, highly engaged audiences interested in their unique offerings (e.g., organic, specific varietals).

H. Vehicles and Robotics (Automation)

- **Relevance:** Automation through robotics and advanced vehicles addresses labor shortages, improves efficiency, increases precision in vineyard and winery operations, and can contribute to worker safety and sustainability.
- **Applications and Adoption (2024):**
 - **In the Vineyard (Precision Viticulture):**
 - **Autonomous Tractors:** For tasks like spraying, mowing, tilling, weeding (e.g., Amos Power electric tractors, Agtonomy-enabled Bobcat, Monarch smart tractors³³). The driverless tractors segment has the largest revenue share in the harvesting robots market.⁷⁹
 - **Robotic Weeding:** Under-vine weeding (e.g., Naïo Ted & Jo⁸⁰; Oxin⁸²).
 - **Robotic Pruning and Leaf Removal:** Optimizing growth and sunlight exposure.⁸⁰ Naïo Ted/Jo are developing pruning.⁸⁰ Modular-E is developing pruning.⁸¹
 - **Robotic Spraying:** Precision spraying (e.g., Robotics Plus Prospr, Exxact Robotics TRAXX⁸¹).
 - **Robotic Harvesting:** Mimicking human picking, cutting stems (e.g., PeK Automotive Grape Picker, MULA berry harvester⁸¹). Harvesting robots market: USD 2.24 billion in 2024, CAGR 21.9%.⁷⁹
 - **Drones (UAVs):** Monitoring vine health, stress levels, data collection.¹⁹ The

- UAV segment is the fastest-growing in harvesting robots.⁷⁹
- **Adoption:** US Vineyards - robots 3%, drones/aerial technology 15%.³⁰
 - **In the Winery (Oenology and Production):**
 - **AI-Powered Optical Sorters:** For grape selection (9% adoption in US³⁰).
 - **Automated Fermentation Monitoring and Control:** (4% adoption in US for AI systems³⁰).
 - **Robotic Cellar Operations:** Barrel management (washing, filling), sampling. Treasury Wine Estates invested \$10M in an end-to-end automation system including driverless forklifts and automated barrel management.³⁸
 - **Robotic Bottling, Packaging, and Palletizing:**²⁹ Semi-automatic machinery leads the market, while fully automatic is growing.²⁹
 - **Logistics and Warehousing:**
 - **Automated Guided Vehicles (AGVs) and Autonomous Mobile Robots (AMRs):** Transporting goods in warehouses.³⁸
 - **Automated Storage and Retrieval Systems (AS/RS).**
 - **Warehouse Management Systems (WMS)** with automation features.⁴⁷
 - **Benefits:** Reduced labor costs, increased operational efficiency and speed, improved precision and consistency, enhanced worker safety, potential for 24/7 operations, data collection capabilities, reduced environmental impact (electric vehicles, optimized spraying).²⁹
 - **Case Studies/Examples:** Naïo Technologies (Ted and Jo robots for weeding, soil work⁸⁰; used by Domaine du Gibeau, Château Fombrauge⁸⁰). SmartMachine Oxin (mowing, leaf removal, spraying⁸²). Amos Power (electric autonomous tractors in CA vineyards⁷⁸). Agtonomy (Bobcat tractor automation, Clemens tools; tested at Trattore Farms, Treasury Wine Estates, Gallo⁷⁸). Yanmar YV01 smart vineyard robot.⁷⁹ Ultrawine Perseo (ultrasound for extraction⁸⁸). Treasury Wine Estates (barrel management, driverless forklifts³⁸).
 - **Challenges:** High initial investment, need for skilled operators/maintenance, vineyard mapping for autonomous navigation⁸², connectivity issues in rural areas, concerns about potential worker displacement⁸², regulations for driverless vehicles.⁸¹

Labor shortages and costs are the main catalysts for robotics adoption. The increasing difficulty in finding and affording skilled agricultural labor⁷⁸ is a more significant driver for robot adoption in vineyards than pure technological curiosity. Robots are seen as a practical solution to a pressing operational problem.

Modularity and versatility are key to vineyard robot ROI. Robots that can perform

multiple tasks (e.g., Naïo Ted with ~20 implements⁸⁰; SmartMachine Oxin⁸²; Modular-E⁸¹) offer a better return on investment for wineries, as the high capital cost can be amortized over a wider range of operations throughout the year, rather than a single seasonal task.

Automation in winery logistics is advancing beyond bottling to complete end-to-end systems. While bottling automation has been common, leading wineries are now investing in comprehensive automation from barrel handling to warehousing (e.g., Treasury Wine Estates³⁸), driven by the need for scale, efficiency, and cost control in post-production logistics.

IV. Advances in Digital and Technological Applications in Vitiviniculture (2024)

The year 2024 has witnessed a continuous evolution and integration of advanced technologies in the wine sector, with a particular focus on resource optimization, quality improvement, and adaptation to a changing environment.

A. Precision Viticulture (PV) as a Cornerstone

Precision Viticulture has established itself as a fundamental approach to modern vineyard management. Its goal is to use technology and data for site-specific management, optimizing grape quality, yield, and resource use.⁸³

- **Key Technologies and Components:**
 - **Sensors:** Soil sensors (moisture, nutrients), plant sensors (water status, health), and weather stations (real-time microclimatic data) are increasingly common.⁶
 - **Remote Sensing:** The use of drones (UAVs) and satellite imagery for vineyard mapping, canopy assessment, vigor map creation, and early detection of diseases or water stress is an expanding practice.⁶
 - **Geographic Information Systems (GIS):** Allow for detailed mapping of terroir, soil, drainage, and the integration of various data layers for spatial analysis.⁶
 - **Global Positioning Systems (GPS) and Guidance Systems:** Essential for precise machinery operation, variable rate application (VRT), and mapping. Technologies like PinPoint RTK offer high precision.²⁴
 - **Variable Rate Technology (VRT):** Enables site-specific application of water, fertilizers, and pesticides based on sensor data and maps, optimizing input use.¹⁹
 - **Software and Data Analytics:** Platforms for data integration, analysis,

modeling, and decision support are crucial.²⁸

- **Market Size and Growth:** The global PV market was valued at \$1.62 billion in 2024, with projections to reach \$1.8 billion in 2025 and \$4.59 billion by 2034 (CAGR ~11%).⁸³ Another source places it at \$1.47 billion in 2024, growing to \$2.45 billion in 2029 (CAGR 10.7%).⁸⁹ The European market accounted for \$599.4 million in 2024.⁸³ The yield monitoring segment had a 40% market share in 2024.⁸³
- **Benefits:** Improved grape quality and yield (a 10-15% increase is reported ⁹⁰), resource use efficiency (reduction in water, fertilizers, pesticides ²⁵), cost savings (profit gains of 10-30% with VRA/remote sensing ⁹²), improved sustainability, and better risk management (diseases, climate).⁶ In Cyprus, a 75% reduction in pesticide use was achieved ³⁸, and in Italy, a 33.4% decrease in GHG emissions.³⁸

The evolution of Precision Viticulture is transitioning from simple data collection to actionable intelligence. It is no longer just about deploying sensors and drones, but about integrating this data with AI/ML for predictive analytics and automated decision support, leading to more tangible benefits in resource use and quality.⁸³ This is a shift from descriptive to prescriptive and predictive analytics.

B. Smart Farming and IoT in Vineyards

Smart farming involves the integration of IoT devices (sensors, actuators, connected equipment) for real-time monitoring and automated control of vineyard operations.⁶ A major focus is connectivity, with technologies like 5G enabling faster data exchange ⁸⁶, and edge computing for local data processing, reducing latency and allowing timely interventions.⁹¹

C. Biotechnological Innovations and New Genetic Improvement Techniques

The OIV is focusing its attention on evaluating resistant varieties and new genetic improvement technologies as sustainable options for climate change adaptation and pest and disease management.⁹³ This includes the development of drought-resistant and disease-resistant grape varieties ⁶, a crucial research area for the sector's future resilience.

As new oenological practices and biotechnologies emerge, OIV resolutions ⁹³ play a vital role in validating, standardizing, and facilitating international acceptance and trade of wines produced with these innovations. This international validation is critical to ensure that wines made with new technologies can be freely marketed and accepted by consumers and regulators globally, preventing technical barriers to trade.

D. Innovations in Oenology and Production Processes

Technological advances are also transforming practices within the winery:

- **Advanced Analytical Techniques:** For quality assurance, instruments like FOSS machines, capable of measuring up to 30 parameters in a single sample ⁹⁷, are used, and analytical methods standardized by the OIV are followed.⁹⁶
- **Precision Fermentation:** Methods seeking greater consistency and control over the fermentation process.⁶
- **Filtration Technologies:** Membrane filtration is being investigated as an innovative alternative to traditional practices, with potential for improved recovery and waste reduction.⁹⁸
- **New Additives and Practices:** The OIV recently approved the use of functionalized mesoporous silica for protein stabilization of wines (Resolution OIV-OENO 672B-2024) and updated monographs on the use of non-Saccharomyces yeasts (Resolution OIV-OENO 740-2024).⁹⁶
- **Emerging Technologies:** The use of ultrasound (Ultrawine Perseo) to enhance compound extraction during winemaking is an example of process innovation.⁸⁸

E. Sustainable Technologies Beyond the Vineyard

Sustainability is a key driver for technological adoption throughout the value chain:

- **Water Conservation in Winery:** Implementation of rainwater harvesting systems and technologies to reduce water consumption in winery operations.⁹⁹
- **Energy Efficiency and Renewable Energies:** Adoption of solar energy (e.g., at Spier Wine Farm ⁹⁹) and other renewable sources to reduce the carbon footprint.
- **Waste Reduction and Circular Economy:** Practices to minimize waste and valorize winemaking by-products (e.g., VSPT uses grape waste for biogas ²⁰; the OIV promotes the circular economy ⁹³).
- **Sustainable Packaging:** Innovations in packaging, such as lighter bottles and alternative formats (bag-in-box, cans), to reduce environmental impact and meet consumer demands.⁶

The drive towards sustainability is increasingly holistic and fuels integrated technological adoption. It is no longer about isolated efforts (like organic farming alone) but encompasses water, energy, waste, and biodiversity across the entire value chain.⁶ This is leading to the adoption of a diverse set of interconnected technologies, from precision irrigation in the vineyard to renewable energy and waste-to-energy systems in the winery, through to lighter packaging.

V. Future Outlook and Strategic Recommendations

The trajectory of digitalization and technological adoption in the wine industry will continue its ascent in the coming years, driven by the need for efficiency, sustainability, and a deeper connection with the consumer. However, the path to a fully digitalized future will require strategic planning, investment in human capital, and continuous adaptation to an ever-evolving technological landscape.

A. Projected Growth of Key Technologies (towards 2030/2035)

Various technological segments relevant to the wine industry show significant growth projections:

- Agritech Market:** The global agritech market is expected to reach \$34.8 billion by 2034, with a Compound Annual Growth Rate (CAGR) of 15.3%.²⁷ North America currently dominates, but Asia-Pacific is projected to be the fastest-growing region.
- Precision Viticulture Market:** Projected to reach approximately \$4.6 billion by 2033/2034 (CAGR ~11%).⁸³
- Wine E-commerce Market:** Forecasted to grow with a CAGR between 7.8% and 8.8%, potentially accounting for over 20% of global wine sales by 2030.²²
- Harvesting Robots Market:** Estimated CAGR of 21.9% for the period 2025-2030.⁷⁹
- AI and IoT:** Strong and continuous growth is expected, integral to the expansion of Agritech and Precision Viticulture. It is estimated that 90% of new enterprise applications will incorporate AI by 2025.⁷³
- Global Wine Market Value:** Projections vary, but one source indicates it could reach \$528.3 billion by 2030 (CAGR 4.6% from 2023)¹¹, while another suggests \$326.2 billion by 2035 (CAGR 5.5%).⁶⁹

Table 2: Projected Market Growth for Key Wine-Related Technologies (until 2030/2035)

Technology/Market	Base Market Size (Year)	Projected Market Size (Year)	CAGR (%)	Main Sources
Global Agritech	\$8,150 M (2024)	\$34,831 M	15.3%	²⁷

		(2034)		
Precision Viticulture	\$1,620 M (2024)	\$4,590 M (2034)	10.98%	83
	\$1,470 M (2024)	\$2,450 M (2029)	10.7%	89
Wine E-commerce	ND (Base 2024)	+\$13,000 M (by 2029)	7.8%	22
	ND (Base 2024)	ND	8.8%	23
Harvest Robots	\$2,240 M (2024)	ND (by 2030)	21.9%	79
Global Wine Market (Value)	\$385,000 M (2023)	\$528,300 M (2030)	4.6%	11
	\$19,096,800 M (2025)*	\$32,620,009 M (2035)*	5.5%	69

Note: M = Millions of USD. The figures from ⁶⁹ appear to have a magnitude error (millions of millions), interpreted as billions for consistency. ND = Not Available.

B. The Evolving Role of Data: Towards Data-Driven Decision-Making

The future of the wine industry will be increasingly defined by its ability to effectively collect, integrate, and analyze data. Greater emphasis will be placed on data integration throughout the entire value chain, from vineyard sensors to consumer purchase data. AI and Machine Learning (ML) will be crucial for extracting value from these large and complex datasets, enabling more accurate predictions, better resource allocation, and a deeper understanding of consumer behavior.³² This, in turn, will require an increase in data literacy and analytical skills within wineries and sector organizations.²⁴

C. The Human Element in a Digital Future

Technological transformation cannot occur in a vacuum; the human factor is paramount.

- **Addressing the Digital Skills Gap:** There is a critical need to upskill and reskill the current workforce so they can effectively operate and manage new

technologies.²⁴ 72% of experts recognize the need for continuous learning.²⁴

- **Change Management:** Overcoming resistance to new technologies and fostering a culture of innovation and adaptability will be essential for successful adoption.²⁶
- **Human-Centric AI:** The concept of Industry 5.0, which emphasizes collaboration between humans and machines, suggests that AI should augment human capabilities rather than replace them entirely.¹⁰² The future is not about total automation replacing human expertise in wine, but rather AI augmenting human skills. Winemakers, viticulturists, and marketing professionals will need to become adept at working *with* AI tools, interpreting their results, and guiding their application.³⁴ Dr. Strever's quote, "AI can summarize and combine data well, but it lacks logic"³⁴, is key here. Winemaking has an artistic and experiential component; AI can optimize processes and analyze data, but human oversight, intuition, and strategic direction will remain crucial.

D. Strategic Recommendations for Technology Adoption

- **For All Wineries:**
 - **Develop a Clear Digital Strategy:** Aligning technology adoption with overall business objectives is fundamental.²⁴
 - **Start with Foundational Technologies:** Establish a solid base with e-commerce platforms, CRM, email marketing, and social media management tools.⁶⁸
 - **Customer Focus:** Use data to understand and meet specific customer needs and preferences.¹⁰
 - **Prioritize Investments:** Evaluate technology investments based on potential ROI and strategic impact.⁷⁴
 - **Invest in People:** Training and change management are as important as the technology itself.²⁴
 - **Embrace Sustainability:** Use technology to achieve and communicate sustainable practices, which are increasingly valued by consumers.⁶
- **For Small vs. Large Wineries:**
 - **Small Wineries:** Should leverage cloud-based SaaS (Software as a Service) solutions, which are more affordable and scalable. Focus on D2C and digital marketing to build direct customer relationships. Explore collaborative technology adoption where feasible.²⁵
 - **Large Wineries:** Have the capacity to invest in comprehensive ERP systems, advanced AI/Big Data analytics, and robotics to achieve economies of scale and efficiency. They should lead in R&D and innovation.²⁵

While technology becomes more accessible (e.g., cloud SaaS for SMEs), the ability to

strategically implement, integrate, and derive maximum value from complex systems (AI, comprehensive ERPs, robotics) could widen the competitive gap between large, well-funded wineries and smaller players if the latter do not receive adequate support or adopt collaborative models. Large wineries can afford dedicated tech teams, R&D, and large-scale implementations (e.g., Treasury's \$10M automation³⁸), while SMEs struggle with initial costs and skills.²⁵

E. The Future of Wine: Key Themes

The future of wine will be marked by several interconnected themes, largely enabled by technology:

- **Personalization:** Tailored wine recommendations, customized products, and targeted marketing will be the norm.¹⁵
- **Sustainability:** Technology will be a key enabler for environmentally and socially sustainable practices across the value chain.⁶
- **Experience:** Lines between physical and digital will blur, offering immersive and engaging experiences (virtual tastings, AR, smart labels).⁶
- **Resilience:** Using technology to adapt to climate change and market volatility will be crucial for long-term survival and success.²

F. Role of Sector Organizations and Collaboration

Organizations like the OIV play a crucial role in shaping the technological future of the sector. The OIV Strategic Plan 2025-2029 focuses on sustainability, resilient viticulture, adaptation of oenology, trade simplification, and consumer safety.⁹³ OIV resolutions on new technologies and practices (e.g., on agroecology, new oenological practices⁹⁴) provide important guidelines and standards. Collaborative research, knowledge sharing, and the establishment of industry standards will remain vital.

As technologies like advanced AI, gene editing for vines, and complex data-sharing platforms become more prevalent, the wine industry will need to proactively engage with regulatory bodies (like the OIV's role⁹³) to establish ethical guidelines, standards, and ensure consumer trust. This will prevent a reactive and restrictive regulatory environment, fostering responsible innovation.

VI. Comparative Analysis: Technology and Digitalization in Key Wine-Producing Countries (2024)

The adoption and focus of technology and digitalization vary significantly among

major wine-producing countries, reflecting their economic contexts, industrial structures, government priorities, and winemaking traditions. Below is a comparative analysis of ten key countries.

Table 3: Comparative Matrix of Technological Adoption in Key Wine-Producing Countries (Estimated Levels 2024)

Technology	France	Italy	Spain	USA	Chile	Argentina	South Africa	Australia	China	Germany
AI & Big Data (General)	Medium	Medium	Medium	High	Medium	Low-Medium	Low-Medium	Medium-High	Medium	Medium
<i>In Precision Viticulture</i>	Medium-High	Medium-High	Medium-High	High	Medium	Low-Medium	Low-Medium	High	Medium	Medium-High
<i>In Marketing /Sales</i>	Medium	Medium	Medium	High	Medium	Low	Low	Medium	Medium-High	Medium
Cloud Computing	High	High	High	Very High	Medium-High	Medium	Medium	High	High	High
Blockchain (Traceability)	Low-Medium	Medium	Low-Medium	Medium	Low-Medium	Low	Low-Medium	Medium	Low-Medium	Low

Cybersecurity (Maturity)	Medium-High	Medium	Medium	High	Medium	Low-Medium	Low-Medium	Medium-High	Medium	Medium-High
E-commerce (D2C)	Medium-High	Medium	Medium	Very High	Medium	Low-Medium	Medium	High	High	Medium-High
ERP (General Adoption)	High	High	High	Very High	Medium-High	Medium	Medium	High	Medium-High	High
<i>Wine-Specific ERP</i>	Medium	Medium	Medium	High	Medium	Low-Medium	Low-Medium	Medium-High	Low-Medium	Medium
Digital Marketing (Advanced)	Medium	Medium	Low-Medium	High	Low-Medium	Low	Low	Medium	Medium-High	Medium
Vehicles/Robotics (Vinyard)	Medium	Low-Medium	Low-Medium	Medium	Low-Medium	Low	Low	Medium	Low-Medium	Low-Medium
Vehi	Low-	Low-	Low-	Medi	Low-	Low	Low	Low-	Low-	Low-

cles/ Rob otics (Win ery)	Medi um	Medi um	Medi um	um	Medi um			Medi um	Medi um	Medi um
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Note: This table is a qualitative estimate based on the information available in the research excerpts. "Low," "Medium," "High," and "Very High" are relative and reflect the general maturity and penetration of each technology in the respective country's wine sector in 2024.

A. France

- **Overview and Digital Maturity:**

- Second largest global producer and second largest vineyard (783 kha, -0.7% vs 2023).¹ Strong focus on quality and export.
- Medium-high digital maturity, with a sector aware of the need for modernization but also strongly rooted in tradition. The French government and the EU are driving digital and ecological transformation.¹⁰⁵

- **Technological Strengths and Weaknesses:**

- **Strengths:** Long tradition in viticultural research that can leverage new technologies. Interest in precision agriculture and alternatives to pesticides.¹⁰⁷ Strong government support for innovation.¹⁰⁸
- **Weaknesses:** Fragmentation in some regions with many small farms that may struggle to adopt costly technologies. Resistance to change in some traditional segments.

- **Government Initiatives, Funding, and Innovation Centers:**

- The European Investment Bank (EIB) approved a €3 billion package in 2024 for agricultural businesses, focusing on generational renewal and ecological transition.¹⁰⁵ Bpifrance has dedicated €9 billion for the transformation of manufacturers and €10 billion to develop the AI ecosystem and facilitate its adoption by French companies.¹⁰⁸
- The French government has ambitious goals for digitalization, robotics, and genetics in agriculture, aiming to halve pesticide use by 2025.¹⁰⁷
- FranceAgriMer manages support programs, including a recent €120 million scheme for vineyard grubbing-up to combat oversupply, with the possibility of additional funds.¹¹⁰ A French scheme of €5 billion was also approved to facilitate wine and spirits exports to the US through a reinsurance mechanism.¹⁰⁹

- EU funding via NextGenerationEU to boost digital transformation.¹⁰⁶
 - Events like Vinexpo Paris¹¹¹ and Vinitech-Sifel in Bordeaux⁸⁰ are important technological and innovation showcases.
 - **Leading Digital Wineries and Technology Adoption:**
 - Large groups like LVMH (Moët Hennessy) and Pernod Ricard Winemakers are investing in sustainability and technology. Pernod Ricard is involved in AI use.²⁶
 - Gérard Bertrand is recognized for his leadership in biodynamics and sustainability, using advanced analytics (FOSS machines) for precision in winemaking.⁹⁷ Although "digitalization" per se is not detailed, large-scale biodynamics implies sophisticated data and process management.
 - Many wineries are adopting QR codes on labels and exploring immersive technologies for wine tourism.⁷⁷
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B. Italy

- **Overview and Digital Maturity:**
 - World's leading producer in 2024 (44.1 Mhl, +15.1% vs 2023, but -6% vs 5-year average) and fourth largest vineyard (728 kha, +0.8% vs 2023), unique among the top 7 with surface area growth.¹ Strong export orientation, especially for sparkling wines like Prosecco.¹⁷
 - Growing digital maturity, with a strong push towards traceability, sustainability, and e-commerce.¹⁷
- **Technological Strengths and Weaknesses:**
 - **Strengths:** Dynamic sector with interest in innovation. Strong quality tradition that can benefit from technology to ensure authenticity. Growing adoption of sustainable and organic practices.¹⁴
 - **Weaknesses:** Sector fragmentation with many SMEs that may face cost and knowledge barriers to technology adoption. Production decreased by 13% in the last year (compared to historical average) in some regions due to climate.¹⁷
- **Government Initiatives, Funding, and Innovation Centers:**
 - The "Terra & Tech" program, launched by Filiera Futura and I3P in December 2024, seeks innovative startup solutions for vineyards (irrigation automation, climate monitoring, predictive analysis with AI, IoT, sensors) and marketing.¹¹⁵
 - Invitalia manages the "Mini Development Contracts" (€300 million) to support investments in strategic technologies (digital innovation, clean technologies, biotechnology) for SMEs and large companies.¹¹⁶
 - EU funds via NextGenerationEU (PNRR in Italy) for digital transformation.¹⁰⁶
 - Vinitaly acts as an important showcase and incubator for trends, focusing on

0.0 technologies and wine tourism.¹¹⁷ The Ministry of Agriculture (MASAF) supports promotion through Vinality.¹¹⁷

- A case study in Italy on smart farming showed a 33.4% decrease in GHG emissions and a 5.3% improvement in intrinsic product quality.³⁸
 - **Leading Digital Wineries and Technology Adoption:**
 - Frescobaldi has significantly improved its digital presence and consumer engagement through its partnership with Vivino since 2019, using the platform's technology (AI, user reviews) and offering content in 10 languages.⁷⁶
 - Antinori and Gaja, historic and prestigious wineries, continuously invest in quality and likely in technologies that support it, although specific details are not in the excerpts.
 - Umani Ronchi, named "Best Italian Winery of 2024" by Gambero Rosso, focuses on excellence, innovation, and sustainability, adopting techniques for pure and authentic wines, and developing wine tourism.¹¹⁹
 - Many Italian wineries are adopting blockchain traceability and sustainable packaging.¹⁷
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C. Spain

- **Overview and Digital Maturity:**
 - World's largest vineyard surface area (930 kha in 2024, -1.5% vs 2023) and third largest EU producer.¹ Export value increased by 1.4% in 2024 to €2.98 billion, despite a 5% drop in volume.¹²²
 - Medium digital maturity, with a sector seeking to improve competitiveness through innovation, especially in precision viticulture and resource management due to climate variability and water scarcity.¹²¹
- **Technological Strengths and Weaknesses:**
 - **Strengths:** Strong export sector, especially for bulk wines, but with increasing focus on higher value-added wines. Adoption of precision viticulture to optimize production and quality.²⁸
 - **Weaknesses:** Dependence on climatic conditions (much of the vineyard is rain-fed). Need for greater digitalization in SMEs.
- **Government Initiatives, Funding, and Innovation Centers:**
 - The Ministry of Agriculture, Fisheries and Food (MAPA) approved €12.15 million of Next Generation funds for 23 innovative projects in the agri-food and forestry sectors (to be implemented by March 2025), with 14 of them focused on resource efficiency, precision and smart agriculture, digitalization, and modernization.¹²⁴

- The Wine Technology Platform (PTV) promotes R&D projects for innovation and quality.¹²¹
 - Spain's CAP Strategic Plan 2023-2027 will allocate €75 million of public spending to innovation initiatives.¹²⁴
 - The SMARTWINERY project, funded by the EU (I3 Facility), includes Spanish partners (University of Murcia, Productos Agrovin, PTV) to develop winery 4.0 technology, optimizing processes and reducing the carbon footprint.¹²⁵
 - **Leading Digital Wineries and Technology Adoption:**
 - Familia Torres received the Golden Vines Innovation Award 2024 for its pioneering work in sustainable and respectful winemaking practices, combining tradition with constant innovation, including the recovery of ancestral varieties and regenerative viticulture projects. Its Innovation and Knowledge department works in viticulture, oenology, microbiology, and technology.¹²⁶
 - Large wineries like Vega Sicilia and Protos likely invest in technology to maintain their high quality standards, although specific digital technologies are not detailed in the excerpts.
 - The sector in general is adopting precision viticulture, with Europe (including Spain) leading in this aspect.²⁸
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D. United States (USA)

- **Overview and Digital Maturity:**
 - World's most dynamic wine market, but with recent headwinds. Market volume declined 10% in 2023, although consumers are spending more on wine.¹⁰ Over 400 million cases expected to be shipped by the end of 2025.¹⁰ Sixth largest vineyard (385 kha, -0.7% vs 2023).¹
 - High digital maturity, especially in D2C, digital marketing, and AI adoption in some segments. The industry needs new data and approaches to connect with younger consumers.¹⁰
- **Technological Strengths and Weaknesses:**
 - **Strengths:** Strong technological innovation ecosystem (Silicon Valley). Leadership in D2C and digital marketing. Early adoption of AI in marketing and some winery operations.³⁰
 - **Weaknesses:** Challenges in connecting with Millennials and Gen Z. Decline in online sales as a percentage of total post-pandemic.¹⁰ Oversupply in some grape segments (California, Washington).¹²
- **Government Initiatives, Funding, and Innovation Centers:**
 - The American Vineyard Foundation (AVF) establishes annual research

priorities, including in 2024: viruses (Red Blotch, Leafroll, Pierce's Disease), climate change (heat events, water stress), vineyard sustainability (water use, input efficiency, labor/chemical reduction), wine sensory-chemistry relationships, and improved winemaking practices.¹²⁷ Funding proposals are announced in May 2025.

- USDA NIFA (National Institute of Food and Agriculture) offers the Specialty Crop Research Initiative (SCRI) to fund critical needs of the specialty crop industry, including wine.¹²⁸
- Wine Industry Network (WIN) recognizes innovations through the WINnovation Awards. In 2024, they awarded Agrovin (Ultrawine Perseo - ultrasound), amaea (smoke taint removal), Verallia (sustainable glass), Verdi (accessible irrigation automation), and Veritiv (sustainable packaging).⁸⁸
- Wine tech startups are seeking funding, such as WineFi in the UK (relevant for investor interest type), which raised nearly £1.1 million in crowdfunding in 2025, with Coterie Holdings as a major minority shareholder.¹²⁹¹²⁸
- **Leading Digital Wineries and Technology Adoption (California, Oregon, Washington):**
 - E. & J. Gallo Winery uses AI to monitor fermentation conditions in real-time, improving consistency and efficiency.³⁴ It has also tested equipment with Agtonomy.⁷⁸
 - Palmaz Vineyards (Napa Valley) adopted the Fermentation Intelligence Logic Control System (FILCS), an algorithmic fermentation control system.³²
 - Constellation Brands and Treasury Wine Estates (which has US operations) are large players investing in technology, although specific US projects are not detailed in the excerpts. Treasury Wine Estates has tested equipment with Agtonomy.⁷⁸
 - Many US wineries use management software like InnoVint, 360Winery, and WineDirect for D2C and winery operations.⁴⁵
 - Deep Sky Vineyard (Arizona, but relevant for its use of US technology) uses Google Cloud Platform and niolabs to manage agricultural data, achieving annual savings of 1.6 million gallons of water, a 75% reduction in human errors, and a 50% increase in production efficiency.³⁹
 - Innovative marketing strategies like "living" wine labels with QR codes, AI-powered virtual sommeliers, and vineyard glamping are being adopted.³⁶

E. Chile

- **Overview and Digital Maturity:**
 - Major Southern Hemisphere producer, with declining vineyards (200 kha

in 2024, -2.4% vs 2023). Wine production in 2024 fell, but a recovery is expected in 2025 (except Chile). Strong focus on export and sustainability.

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- Developing digital maturity, with a strong drive towards certified sustainability and adoption of technologies for water efficiency and climate resilience.
- **Technological Strengths and Weaknesses:**
 - **Strengths:** Leadership in sustainability programs (Wines of Chile Sustainability Code). Adoption of precision agriculture and water management technologies by large wineries.
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 - **Weaknesses:** Potential gap between technologically advanced large companies and smaller producers.
- **Government Initiatives, Funding, and Innovation Centers:**
 - The Wines of Chile Sustainability program, launched in 2010 and coordinated by Consorcios del Vino (Vinnova-TecnoVid) with the University of Talca, establishes a national code of sustainable practices and an accreditation system. It includes specific projects in social responsibility (GRI reports).
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 - CORFO (Production Development Corporation) supports innovation in various sectors, although specific programs for wine digitalization are not detailed in the excerpts. ChileMass organizes innovation events (ChileMass Innovation Day) to connect the ecosystems of Chile and Massachusetts, with CORFO participation, and Chilean wine is a prominent feature.
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 - The Chilean government is promoting key initiatives for mining activity, such as the National Lithium Strategy, with a focus on sustainability and the adoption of new technologies (automation, AI) , which could have indirect effects or learnings for other export sectors like wine. InvestChile promotes foreign investment, focusing on energy, mining, and global services/technology.
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- **Leading Digital Wineries and Technology Adoption:**
 - Viña Concha y Toro is a regional leader in precision agriculture, using drone imagery and AI for yield forecasting and harvest optimization. It was also the first winery globally to measure its water footprint (2010)

and introduced an internal carbon price in 2022. Its Center for Research and Innovation (CRI), inaugurated in 2014, develops new technologies in viticulture and oenology, with over 80 R&D initiatives, highlighting advances in AI and climate change adaptation.

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- Montes Wines is recognized for its focus on quality, sustainability, and a modern winery (Apalta) with cutting-edge technology and feng shui-based design, which minimizes wine

F. Argentina

Overview and Digital Maturity:

Fifth-largest producer worldwide, with almost 220,000 ha of vineyard.¹³⁷ Production rebounded in 2024 (+23.3 % to 10.9 Mhl) after the previous year's short crop.³ The sector faces high inflation, which pushed revenue up through higher prices despite a drop in domestic sales volume in 2024.¹³⁸ Exports grew in 2024.¹³⁸

Emerging digital maturity, with a growing focus on sustainability and on differentiation through terroir and quality. Digitalisation is viewed as a way to sharpen competitiveness.

Technological Strengths and Weaknesses:

Strengths: Strong wine culture and rising international recognition of Malbec and other varieties. Interest in precision viticulture and terroir expression.¹³⁹ Active sustainability programmes.¹³⁷

Weaknesses: Economic instability and inflation can hinder long-term tech investment. Smaller wineries need higher tech adoption.

Government Initiatives, Funding and Innovation Centres:

The National Institute of Agricultural Technology (INTA) is a key federal agency for developing and spreading agricultural technology, including for wine.¹⁴⁰ It provides experimental stations, labs and vineyards for research and involves students in projects.

Wines of Argentina (WOA) leads promotion and sustainability work such as the “**Sustenta-Vitis**” programme (181 wineries accredited as sustainable in August 2023) and creates content for interactive digital media.¹³⁷

Bodegas de Argentina has run a “**Wine-growing Sustainability**” seal since 2010 and works on streamlining regulation.¹³⁷

The Argentine government has agreed a US \$20 billion IMF stabilisation programme centred on a strong fiscal anchor, a tougher monetary/exchange-rate regime and market-friendly reforms—deregulation and a new regime to attract big investment in strategic sectors (mining, energy, renewables).¹⁴² Though not wine-specific, a steadier

economy could ease tech investment.

Sitevintech Argentina is the most important wine trade fair in Latin America, showcasing the latest vineyard and ag-tech trends.¹⁴⁴

Leading Digital Wineries and Tech Adoption:

Catena Zapata (Adrianna Vineyard) is famed for terroir research and high-scoring wines—implying sophisticated data and vineyard analytics.¹⁴⁵ The estate works with AI.²⁶

Zuccardi Valle de Uco pursues deep terroir knowledge and micro-terroir mapping, using precision viticulture to express place identity.¹³⁹

Wineries such as Chakana Winery and Grupo Avinea (Otronia, Bodega Argento) also focus on precision viticulture and gentle, terroir-respectful winemaking.¹³⁹

Altos Las Hormigas produces organic, sustainable Malbec noted for site-specific precision.¹⁴⁵

Argentine wineries practising sustainable farming tend to have greater tech and human resources and apply innovative product strategies.¹³⁷

G. South Africa

Overview and Digital Maturity:

Wine-grape output in 2024 was the lowest since 2002 owing to bad weather, though improvement is expected in 2025. Vineyard area is shrinking.¹⁴⁶ The sector counts 2,350 growers and 522 wineries—71 % small.¹⁴⁶

Digital maturity is advancing, with a strong tilt toward sustainability, R&D and social transformation within the industry.

Technological Strengths and Weaknesses:

Strengths: Well-organised industry with robust R&D through South Africa Wine. Leader in some sustainable winemaking practices.⁹⁹ Global recognition for brandy and wine quality.¹⁴⁸

Weaknesses: Producers' cash-flow limits can curb tech spending. Some regions have ageing vineyards.¹⁴⁶

Government Initiatives, Funding and Innovation Centres:

South Africa Wine (SAW) leads the Research, Development & Innovation (RDI) strategy, funding academic work on vineyard management, pest and disease control, quality, climate adaptation, water efficiency, soil health and wine authenticity.⁹ SAW's 2024 research book details the projects.

Flagship SAW RDI programmes tackle climate change, water use, genetics and

authenticity—including a blockchain ecosystem for South African wine and an ESG roadmap.⁹

In 2024 SAW launched a Graduate Placement Programme linking graduates (especially Black) to sector firms in viticulture, winemaking, logistics, export and industrial engineering; SAW contributes R5,000 a month toward each salary.¹⁴⁹

SAW's Transformation Department targets social sustainability, Black-owned business growth and ethical trade, in line with the Agricultural & Agro-processing Master Plan (AAMP).¹⁵⁰ **The Wine Arc** is evolving into a knowledge and enterprise hub.¹⁵⁰

Winetech South Africa also funds and steers research.

Leading Digital Wineries and Tech Adoption:

KWV was named Best Producer at the 2024 Veritas Awards for the second year running and has won multiple brandy prizes, underscoring its innovation drive.¹⁴⁸

Reyneke Wines (Stellenbosch) is noted for biodynamic vineyards.⁹⁹

Waterkloof Wine Estate (Somerset West) captures rainwater for reuse.⁹⁹

Spier Wine Farm (Stellenbosch) has a large solar array covering a big share of energy needs.⁹⁹

Dr Albert Strever (Stellenbosch University) notes that AI can merge and summarise data but lacks logic, so human expertise remains vital—showing active AI debate in South African viticulture.³⁴

H. Australia

Overview and Digital Maturity:

Wine production in 2023-24 hit 1.04 billion litres—up 8 % on 2022-23 but still the second-lowest since 2006-07. White-wine output topped red for the first time since 2011-12.¹⁵¹ The 2024 grape crush was 1.43 million tonnes, 9 % above 2023 yet 18 % below the 10-year average.¹⁵² A surplus of red wine is a major issue.¹⁵² China lifted tariffs on Australian wine in April 2024.¹⁵²

Digital maturity is relatively high, especially through R&D bodies such as AWRI and Wine Australia. There is a strong focus on sustainability and climate adaptation.

Technological Strengths and Weaknesses:

Strengths: Strong R&D base. Widespread sustainable-viticulture uptake (Sustainable Winegrowing Australia covers 51 % of vineyard area and 71 % of the national crush).¹⁵² Innovation in winemaking tech such as membrane filtration.⁹⁸

Weaknesses: Repeated small harvests squeeze R&D budgets.¹⁵² Red-wine oversupply poses financial challenges.

Government Initiatives, Funding and Innovation Centres:

Wine Australia backs R&D with AWRI, grouped into insights, impact and extension/adoption.¹⁵²

The Australian Wine Research Institute (AWRI) tackles smoke taint, wine stabilisation, Brettanomyces diagnostics and supports uptake of new tech; it also runs advanced courses and extension.¹⁵²

Sustainable Winegrowing Australia (AWRI, Wine Australia, Australian Grape & Wine) promotes best practice.¹⁵²

The federal Support Regional Trade Events stream funds AgriFutures' Agritech Event Sponsorship Program (A\$400 k for regional agritech events, A\$100 k for R&D bodies) to spur adoption.¹⁵⁶

The Australian Research Council (ARC) funds **Mid-Career Industry Fellowships**, e.g. a A\$1.14 m project (2024-29) to speed membrane-filtration uptake, led by Adelaide University with VAF MEMSTAR and AWRI.⁹⁸

Australian Grape & Wine (AGW) is seeking extra federal funding in the 2025 budget—A\$78 m for export promotion, A\$30 m for sustainability support and A\$20 m for a national marketing campaign.¹⁵³

Leading Digital Wineries and Tech Adoption:

Treasury Wine Estates (Penfolds) is among the biggest producers and invests heavily in tech and sustainability. In July 2024 it rolled out a A\$10 m end-to-end automation system featuring custom barrel-management software, automated barrel washing/filling, barrel ID and nine driverless forklifts.³⁸ Penfolds also explores AI.²⁶

Accolade Wines and Casella Family Brands are other major players likely using advanced tech for large-scale operations.¹⁵⁷

Family estates such as Henschke, Yalumba and Seppeltsfield are famed for quality and heritage; Seppeltsfield stresses its innovative 1888 Gravity-Flow Winery and sustainability focus.¹⁵⁸

Across the sector, precision agriculture and digital solutions for vineyard and winery management are spreading, as seen in AWRI projects and agritech funding.¹⁵⁵

Wine Australia's Australian Wine Showcase events highlight innovation and sustainability in promoting the nation's wines.¹⁵⁹

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