

Artificial Intelligence in Precision Viticulture: A pathway to sustainable and smart vineyard management

ABSTRACT

Motivation for Choosing This Topic

As a systems engineer specialized in artificial intelligence and a certified WSET Diploma holder, I pursued this thesis as a natural convergence of my dual passions: advanced technology and the world of wine. The wine industry, traditionally rooted in empirical knowledge and artisanal practices, is now facing an unprecedented crossroads shaped by climate change, resource scarcity, and market demands for sustainable, socially responsible production. I sought to create a study with tangible, long-lasting impact by addressing these environmental and operational challenges through cutting-edge AI applications in precision viticulture.

In parallel, AI has become a highly relevant, rapidly evolving field, making it an opportune time to raise awareness and promote structured AI adoption in the wine sector. By exploring how artificial intelligence can optimize resource use, reduce environmental footprint, and enhance decision-making in vineyards, this thesis aims to position AI not as a futuristic concept but as a strategic and accessible tool for today's wine producers.

Problem Statement / Objectives

The primary objective of this thesis was to investigate how artificial intelligence can be effectively integrated into precision viticulture practices to improve environmental sustainability, operational efficiency, and vineyard resilience against climate change.

Specific objectives included:

- Evaluating AI's potential to optimize irrigation, fertilizer, and pesticide use.

- Analyzing AI's role in real-time vineyard monitoring, disease prediction, and yield forecasting.
- Developing a strategic, actionable framework for AI adoption tailored to the wine value chain.
- Conducting a survey study among Spanish industry leaders to assess awareness, readiness, and perceived value of AI.

Methodology

The research employed a mixed-method approach:

- **Literature review** on AI in precision agriculture and viticulture, case studies, and environmental challenges.
- **Survey study** targeting prominent wine producers and technical managers in Spain to assess current AI awareness, adoption levels, and perceived barriers.
- **Development of the AI&WINE Framework**, a modular AI implementation model adapted for wineries, using ecosystem mapping, AI use-case matching (with a 150-card toolkit), solution design canvases, and feasibility assessments.
- **Case study analysis** of international AI deployments in vineyards.
- **Data synthesis** through qualitative and quantitative methods to identify trends, opportunities, and adoption strategies.

Content Summary

- **Chapter 1:** Introduces the sustainability pressures facing viticulture, emphasizing climate change's impact on winegrowing regions and the need for advanced technological solutions.

- **Chapter 2:** Details environmental and operational challenges in traditional viticulture, including excessive chemical inputs, soil degradation, and water scarcity.
- **Chapter 3:** Presents AI applications in viticulture, from machine learning disease models to smart irrigation and drone-based multispectral monitoring, supported by international case studies from Rioja, Napa, and Australia.
- **Chapter 4:** Examines barriers to AI adoption — cost, expertise gaps, resistance to change — and limitations such as data bias and ethical concerns. Includes survey findings reflecting high interest but low operational maturity in AI adoption in Spain.
- **Chapter 5:** Proposes the AI&WINE Framework, an innovative, scalable implementation model guiding wineries to identify AI opportunities, match them with appropriate AI use cases, evaluate technical and ROI feasibility, and design tailored solutions.
- **Chapter 6:** Concludes with actionable recommendations for wineries and calls for strategic investments in AI literacy, data infrastructure, and pilot initiatives.

Conclusions

This thesis demonstrates that artificial intelligence offers a significant opportunity to transform viticulture into a data-driven, sustainable, and precision-oriented discipline. The survey results confirmed an emerging interest among industry leaders, albeit constrained by technical and cultural barriers. AI applications in resource optimization, disease management, and yield prediction show quantifiable benefits, both environmentally and operationally.

The **AI&WINE Framework** serves as a practical, accessible roadmap for wineries, ensuring AI adoption is strategic, scalable, and aligned with sustainability goals. By framing AI not as a disruptive threat but as a decision-support tool that complements winemakers' expertise, this research contributes to the evolution of viticulture towards resilience, quality, and ecological stewardship in the face of climate challenges.