Making sense of available information for climate change adaptation and building resilience into wine production systems across the world

Antonio Graça[1*] and Mark Gishen[2]

[1]Sogrape Vinhos, S.A., 4430-852 Avintes, Portugal
[2]Gishen Consulting, Adelaide SA 5000 Australia

***Corresponding author:** antonio.graca@sogrape.pt

Keywords: climate change, adaptation, resilience, risk, viability

Abstract

Effects of climate change on viticulture systems and winemaking processes are being felt across the world. Previously, we presented conceptual guidelines for a 5-stage *Climate Change Adaptation Framework* (CCAF), for defining adaptation strategies for wine businesses. This framework allows for direct comparison of different solutions to mitigate climate change risks. Recent global climatic evolution and multiple reports of severe events since then (smoke taint, heatwave and droughts, frost, hail and floods, rising sea levels) imply urgency in providing effective tools to tackle multiple risks. A coordinated drive towards a higher level of resilience is required. We present examples of practical application of CCAF to impacts affecting production in two wine regions: Barossa (Australia) and Douro (Portugal). We demonstrate using the framework for climate adaptation from available data and as a tool to estimate historical climate-induced profitability loss. Finally, from projecting trends into the future, we discuss adaptation measures and respective timeframes for successful mitigation of disruptive risk while enhancing resilience of wine systems.

Introduction

Effects of climate change on viticulture systems and winemaking processes are being felt across the world (Costa et al., 2020, Hofmann et al. 2021, Quénol & LeRoux 2021). In a previous work we have shown the ability of the wine sector to adapt to climate change as being largely constrained in a relatively consistent manner across the world, with very similar barriers being identified in several countries. We suggested the development of a simple framework, based on a hazard risk analysis and critical control point approach, allowing individual wine regions to choose appropriate adaptation response options for their own relevant adaptation strategies (Gishen et al. 2016). The application of the same framework would foster knowledge sharing across the world in tackling this major challenge.

The International Panel on Climate Change published its sixth assessment report (IPCC, 2021) stating that the scale of recent changes across the climate system are unprecedented over many centuries to many thousands of years. The report indicates that global surface temperature will continue to increase until at least mid-21st century under all emissions scenarios considered, particularly over land areas. The report states any changes due to past and future greenhouse gas emissions are irreversible for centuries to millennia.

The wine sector's ability across the world to adapt to climate change has been largely constrained in a consistent manner, the most important barrier being the gap in access to meaningful predictive climate data projections, and the capacity and ability to use predictive data that does exist (Gishen et al. 2016). However, in recent times, resources have been developed to bridge that gap, including examples in Australia and Europe.

In Australia, an atlas of climate information for all Australian wine regions was published (Remenyi et al. 2019), providing information about climate trends for the near, mid- and long-term horizons. In Europe, a consortium of industry, research and meteorological organisations (Horizon 2020-funded project MED-GOLD) developed a climate services platform prototype to deliver seasonal and long-term (to 2100) climate projections together with historical climate information in high-resolution (up to 1 km) for three key crops of the Mediterranean area: grapes, olives and durum wheat (BSC, 2021).

In this work, we expand and demonstrate the previously proposed (Gishen et al. 2016) *Climate Change Adaptation Framework (CCAF)* to identify adaptation measures and respective timeframes for successful management of disruptive risks while enhancing resilience of wine production systems. We present examples from two very different wine regions: Barossa (Australia) and Douro (Portugal), to demonstrate the feasibility of the framework for climate change adaptation planning in any geographical context.

Materials and methods

The risk assessment was based on the HACCP (hazard analysis and critical control point) approach (Corlett & Pierson, 1992). A new risk analysis model was developed by modifying that described previously (Gishen et al. 2016) to add a third dimension of risk management, degree of intervention, to likelihood and severity. This third dimension considers the fact that costlier adaptation options will reduce adaptation drive and priority. The three-dimensional risk matrix is represented pictorially in Figure 1. We propose that the resulting driver score is a measure of risk significance that can be a measure of priority for the different adaptation options . The hazards can then be assessed to determine if they are critical control points (CCPs) in the same manner as for HACCP food safety systems (FAO, 1998).

Climate is a fundamental feature providing distinctive characteristics for wines originating from a specific area (OIV, 2010). The analysis of long datasets of climate and crop variables allow identification of correlations that inform on potential causal relationships that may be used to simulate direct and indirect impacts of climate scenarios different from those having occurred in the past (Droulia & Charalampopoulos 2021, Hewer & Gough 2021, Strub & Loose 2021).

The availability of long series of climate data (Buontempo et al. 2020) can be coupled with sets of crop data to (i) identify correlations hinting at causal relationship explaining the effect of climate in crops (Costa et al. 2020) and (ii) discover trends to characterize the recent evolution path of the production system and respective business model (Droulia & Charalampopoulos 2021). We studied historical information from two very distant and different wine areas producing high-value wines where climate change has been constraining the viability of the respective business models: the Douro Valley of Portugal and the Barossa Valley of South Australia.

Barossa Valley

The Barossa is a leading Australian wine region located NE of the city of Adelaide, South Australia. The GI region has a total of 11,609 hectares of vineyards (Wine Australia, 2021). Grape harvest data used for this case study were sourced from the control vines of a vineyard trial site at the Nuriootpa Research Station (34°S, 139°E, 284 m a.s.l.) as described by Bonada et al. (2020). Treatments were harvested when total soluble solids (TSS) reached approximately 14 Baume. Total soluble solids (TSS) and juice pH and titratable acidity (TA, g/L tartaric acid) were measured with a calibrated Oenofoss FTIR spectrophotometer (FOSS, Hillerød, Denmark). We evaluated the situation where impact from climate change causes pH and TA to deviate from the 'target', while sugar level meets the specification as closely as possible. The deviation from a defined 'optimum target' composition of 14 Baume, pH 3.5 and TA 6.8 g/L, was used to estimate the 'quality penalty' on the price, hence the net revenue to the grower for each year calculated by subtracting the price penalty and the average production cost from the regional average purchase price for grapes.

Douro Valley

The Douro Wine Region is home to the oldest wine appellation in the world. It currently has 43 708 hectares of vineyards (IVDP, 2020) set in a mountainous area of NE Portugal along the upper Portuguese course of river Douro and its tributaries. Our analysis was conducted on a vineyard block (S59) of 1.14 hectares located at 41.1726°N, 7.5537°W, with an average altitude of 115 m a.s.l. and 23,5% slope steepness, facing west (mean azimuth: 281°). Grapevines were planted in 1985 along vertical rows at right angles to altitude isolines, at 2,2 m x 1,0 m spacing (row x line), grafted onto 1103 Paulsen rootstocks, trained to double Guyot cordons and rainfed. Two sub-blocks of equal area and plant number were grafted with two different varieties: Touriga Francesa (TOF, syn. Touriga Franca – PRT52205) and Tinta Roriz (ARA, syn. Aragonez, Tempranillo – PRT52603), these two varieties representing 38% of the total regional vineyard area (TOF – 10 121 ha, ARA – 5 960 ha. IVV, 2018). Every year from 1991 to 2017, one week before the harvest date, berry weight data was collected at each varietal sub-block of S59 as part of the annual maturity control by randomly sampling 200 berries in both sides of two fixed rows per varietal sub-block. Samples weighed with a calibrated laboratory digital scale with decigram precision, and divided by 200 to obtain the berry weight for recording in a historical database file using Microsoft Excel. Berry weight values were converted into net profit per hectare values by using the following equation:

Equation 1

$$NP = \left(\frac{Bw \times Bb \times Pb \times Stw}{1000} \times Pd \times Gp\right) - Opex$$

where:

NP: net profit in euros per hectare
Bw: berry weight in grams
Bb: average number of berries per bunch typical of the variety in the region (ADVID[1])
Pb: average number of bunches per plant typical of the variety in the region (ADVID[1])
Stw: compensation factor for stalk weight (Blackford et al. 2021)
Pd: plant density in plants per hectare (4 410 plants per ha)
Gp: grape price in euros per kilo (3-year average, 50% Douro and 50% Port)
Opex: operational expenses in euros per hectare (6-year average values of farming costs)

Results and discussion

In the Barossa Valley, whilst the sugar level (Baume) was maintained over the years consistent with the harvest criteria, there was a marked downward trend in titratable acidity and a commensurate increase in pH, consistent with what might be expected from a warming climate trend. It is noteworthy that net return currently is not high, despite the Barossa Valley being a region of world-renowned wines, and more importantly, there is a portentous downward trend. This suggests growers' financial viability is already under considerable growing pressure.

In the Douro Valley, a downward trend in berry weight and, consequently, net returns per hectare is visible for both varieties, ARA showing a faster decrease than TOF. The same is visible in the upper and lower limits of variation. Interestingly, since 2010, values seem less variable which may reflect some adaptation measures already being implemented to protect yields (pruning, canopy management, application of kaolin, etc.) from higher temperatures and lower humidity conditions (Mira de Orduña 2010).

From both analyses, it is evident that there is a future risk of further loss of economic viability for growers. Under a business-as-usual scenario, at a certain point in the future, wineries producing the current styles of wine will most likely be unable to get sufficient supply of fit-for-purpose grapes and will also have little economic interest in growing it themselves.

Adaptation interventions may be, among others, for (A) Barossa: (i) setting up a misting system or, (ii) installing shading structures in the vineyard to reduce heat and evapotranspiration to retain grape acidity, or (iii) earlier harvesting to a target acidity rather than sugar; and for (B) the Douro, (i) setting up an irrigation system as the vineyard is close to the River Douro, (ii) regrafting with heat-sturdier varieties or (iii) to pluck off and replant at higher altitude and less sun-exposed slope aspect. The modified CCAF risk assessment we propose allows to establish the relative priority between options in both cases.

Respective adaptation driver scores to identify adaptation priorities are presented in Table 1. It becomes clear that, in the Barossa, earlier harvest would be the only adaptive measure attaining high priority, whereas for the Douro, irrigation and regrafting would both be medium priority, regrafting edging on high priority. These examples illustrate how the proposed framework can help decide the priority for adaptation options to different risks in different regions. The priorities may also be applied as sequential measures as the climate change impact becomes more prevalent or frequent, putting pressure on net economic returns.

Conclusion

Responding to climate change challenges requires an understanding of nexuses between climatic drivers, physiological responses of the grapevine and respective economic impacts. The application of our proposed framework (CCAF) in two very different and almost antipodal wine regions, allowed us to demonstrate how it is possible to identify those nexuses, draw on historical records to assess risk severity, identify adaptation options and assess their priority driver score to support decision-making. In the periods we analysed, a trending

---

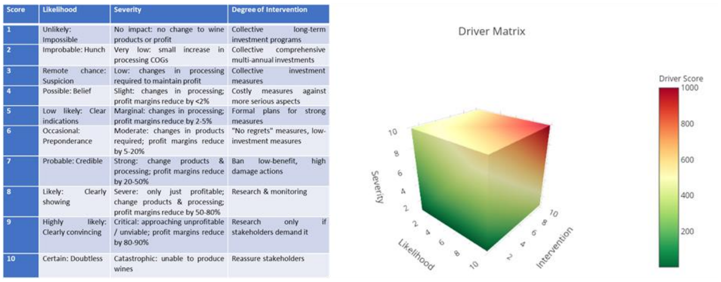
[1] ADVID reference network data, www.advid.pt

economic loss in the business of growing grapes is visible for both wine regions. Projecting those losses into the future allows the simulation of alternative scenarios to a business-as-usual situation. Coupling this approach with the viability theory (Aubin & St. Pierre 2007) further enables the identification of the future moment when business-as-usual is likely to be disrupted, as well as inform the business case for adaptation, based on the estimation and avoidance of future economic losses (paper in preparation). CCAF may in this way become a useful tool for the global wine sector.

Table 1. Calculation of the adaptation driver score for the risk of losing economic viability.

Risk dimensions	Likelihood	Severity	Degree of intervention	Adaptation driver score
Barossa adaptation				
• Misting	9	9	6	486
• Shading	9	9	4	324
• Early harvest	9	9	8	648
Douro adaptation				
• Irrigation	9	9	6	486
• Regrafting	9	9	7	567
• Transfer	9	9	2	162

Adaptation driver score values result from the multiplication of the 3 risk dimensions and range from 1 to 1000 (<200 – low-priority, ≥200 and <600 – medium-priority, >600 – high-priority).



Score	Likelihood	Severity	Degree of Intervention
1	Unlikely: Impossible	No impact: no change to wine products or profit	Collective long-term investment programs
2	Improbable: Hunch	Very low: small increase in processing COGs	Collective comprehensive multi-annual investments
3	Remote chance: Suspicion	Low: changes in processing required to maintain profit	Collective investment measures
4	Possible: Belief	Slight: changes in processing; profit margins reduce by <2%	Costly measures against more serious aspects
5	Low likely: Clear indications	Marginal: changes in processing; profit margins reduce by 2-5%	Formal plans for strong measures
6	Occasional: Preponderance	Moderate: changes in products required; profit margins reduce by 5-20%	"No regrets" measures, low-investment measures
7	Probable: Credible	Strong: change products & processing; profit margins reduce by 20-50%	Ban low-benefit, high damage actions
8	Likely: Clearly showing	Severe: only just profitable; change products & processing; profit margins reduce by 50-80%	Research & monitoring
9	Highly likely: Clearly convincing	Critical: approaching unprofitable / unviable; profit margins reduce by 80-90%	Research only if stakeholders demand it
10	Certain: Doubtless	Catastrophic: unable to produce wines	Reassure stakeholders

Figure 1. CCAF risk analysis model
Scores and descriptions of the three dimensions used in estimating the adaptive driver priority towards action

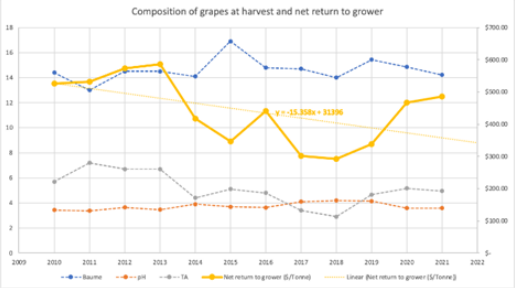


Figure 2. Barossa evolution of composition of grapes at harvest and net return to grower
Trend of grape composition at harvest and the estimated net return to the grower for Barossa Shiraz grapes between 2010 and 2021.

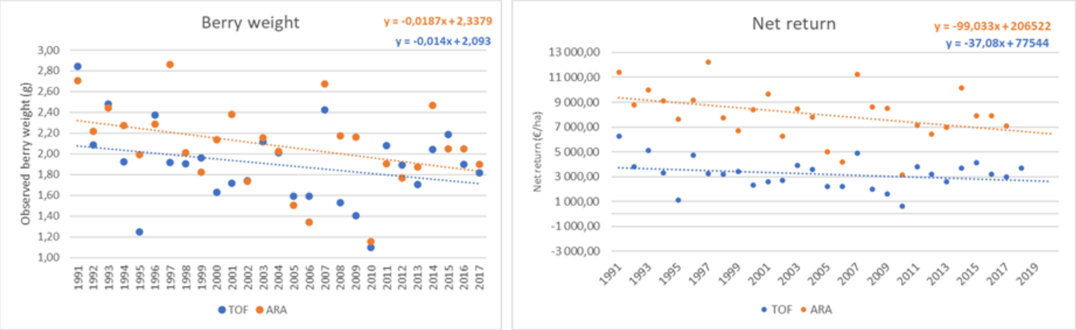


Figure 3. Douro evolution of berry weight at harvest and net return to grower
Trend of berry weight at harvest and corresponding estimated net return to the grower for Touriga Francesa (TOF) and Tinta Roriz (ARA) grapes between 1991 and 2017

References

Aubin, J. P., & Saint-Pierre, P. (2007). An introduction to viability theory and management of renewable resources. *Advanced Methods for Decision Making and Risk Management in Sustainability Science*, 43-80.

Blackford, M., Comby, M., Zeng, L., Dienes-Nagy, Á., Bourdin, G., Lorenzini, F., & Bach, B. (2021). A Review on stems composition and their impact on wine quality. *Molecules*, 26(5), 1240. https://doi.org/10.3390/molecules26051240

Bonada, M., Jeffery, D.W., Petrie, P.R., Moran, M.A. and Sadras, V.O. (2015) Impact of elevated temperature and water deficit on the chemical and sensory profiles of Barossa Shiraz grapes and wines. *Australian Journal of Grape and Wine Research* 21, 240– 253. https://doi.org/10.1111/ajgw.12142

BSC – Barcelona Supercomputing Center (2021). MED-GOLD DASHBOARD for wine sector users. Downloaded from https://www.med-gold.eu/wp-content/uploads/2021/09/MED-GOLD_infosheet08_dasboard_wine_EN_v2.pdf on 30 December 2021.

Buontempo, C., Hutjes, R., Beavis, P., Berckmans, J., Cagnazzo, C., Vamborg, F., Thépaut, J.N., Bergeron, C., Almond, S., Amici, A., Ramsamy, S. & Dee, D. (2020). Fostering the development of climate services through Copernicus Climate Change Service (C3S) for agriculture applications. Weather and Climate Extremes, 27, [100226]. https://doi.org/10.1016/j.wace.2019.100226

Corlett, D. A., & Pierson, M. D. (1992). HACCP: definitions and principles. In *HACCP* (pp. 6-7). Springer, Boston, MA. https://doi-org.libproxy.viko.lt/10.1007/978-1-4684-8818-0_2

Costa C., Graça A., Fontes N., Teixeira M., Gerós H. & Santos J.A. (2020). The Interplay between Atmospheric Conditions and Grape Berry Quality Parameters in Portugal. *Applied Sciences*, 10(14), 4943. https://doi.org/10.3390/app10144943

Droulia, F., & Charalampopoulos, I. (2021). Future Climate Change Impacts on European Viticulture: A Review on Recent Scientific Advances. *Atmosphere*, 12(4), 495. https://doi.org/10.3390/atmos12040495

FAO (1998). *Food Quality and Safety Systems - A Training Manual on Food Hygiene and the Hazard Analysis and Critical Control Point (HACCP) System*. Food and Agriculture Organization of the United Nations, Rome. ISBN 92-5-104115-6. https://www.fao.org/documents/card/en/c/4dbafa30-9c32-5dc2-bf3c-644759a2fc30/

Gishen M., Graça A., Jones G.V. (2016) Proposal for the development of a framework for a globally relevant wine sector climate change adaptation strategy. *XI International Terroir Congress*, Willamette Valley, OR. https://doi.org/10.13140/RG.2.2.11875.14883

Hewer, M. J., & Gough, W. A. (2021). Climate change impact assessment on grape growth and wine production in the Okanagan Valley (Canada). *Climate Risk Management*, 33, 100343. https://doi.org/10.1016/j.crm.2021.100343

Hofmann, M., Volosciuk, C., Dubrovský, M., Maraun, D., & Schultz, H. R. (2021). Downscaling of climate change scenarios for a high resolution, site–specific assessment of drought stress risk for two viticultural regions with heterogeneous landscapes. *Earth System Dynamics Discussions*, 1-26. https://doi.org/10.5194/esd-2021-9

IPCC. (2021). Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

IVDP (2020). Área de vinha e sua composição. https://areareservada.ivdp.pt/estatisticas_novo2.php?codIdioma=0&codEstatistica=2&entnum=&codLogin=&verificationKey=&periodos=897 (downloaded 29 December 2021).

IVV (2018). *Anuário 2018 - Vinhos e aguardentes de Portugal*. IVV, Lisboa.

Mira de Orduña, R. (2010). Climate change associated effects on grape and wine quality and production. *Food Research International*, 43(7), 1844-1855. https://doi.org/10.1016/j.foodres.2010.05.001

OIV (2010). Definition of vitivinicultural terroir, *Resolution OIV/VITI 333/2010*.

Quénol, H., & Le Roux, R. (2021). The Spatial Impacts of Climate Change on Viticulture Around the World. *Spatial Impacts of Climate Change*, 225. https://doi.org/10.1002/9781119817925.ch11

Remenyi, T.A., Rollins, D.A., Love, P.T., Earl, N.O., Bindoff, N.L., Harris, R.M.B. (2019). *Australia's Wine Future – A Climate Atlas*, University of Tasmania, Hobart, Tasmania. Accessed on-line 29 December 2021 from the University of Tasmania at https://eprints.utas.edu.au/32250/

Strub, L., & Loose, S. M. (2021). The cost disadvantage of steep slope viticulture and strategies for its preservation. OENO One, 55(1), 49-68. https://doi.org/10.20870/oeno-one.2021.55.1.4494

Wine Australia (2021). Barossa Valley. https://www.wineaustralia.com/market-insights/regions-and-varieties/south-australia-wines/barossa (downloaded 29 December 2021).