Mitigation and adaptation strategies for a carbon neutral grape and wine sector

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Abstract. The Australian grape and wine sector has committed to reducing its carbon footprint by an active mitigation policy, concentrating in the shorter-term future on reducing Scope 1 and 2 emissions. Life cycle analyses for the sector indicate that carbon emission from grape growing and winemaking are small at 17% and 19% respectively; the major contribution of 68% is to do with packaging and transport (Scope 3), primarily involving use of glass bottles. Diesel use in vineyards is 41% of emissions and may be replaced with difficulty by vehicle electrification and/or hydrogen power. Replacement of winery grid-electricity use will account for 81% of emissions, with conversion to solar currently favoured. Opportunities exist to convert vineyard and winery biomass waste streams using pyrolysis to energy and biochar, the latter a form of sequestered carbon. The remaining large carbon emission relates to traditional use of glass packaging, with inherent weight and volume inefficiency increasing transport costs. Alternate packaging with lower carbon footprint and enhanced recyclability offers promise. The retail sector has opportunities to engage in "replace, recycle, or re-use" practices to reduce this footprint. The wine sector shares an ethical responsibility to mitigate climate change, not least because of impacts on grape and wine production.

1 Introduction

The concept of a climate crisis is now well recognised, with climate scientists warning of the danger of not halting global warming. This arises because of the continued increase in carbon dioxide and other so-called "greenhouse gases" which trap solar energy and hence warm the atmosphere. Such a mechanism is well known to science. The Swedish chemist Arrhenius predicted in 1895 that combustion of fossil fuels would lead to such an increase in global temperatures. Modern scientists have shown that such warming can lead to changes in the climate by affecting all weather systems. Fossil fuel combustion has increased since the industrial revolution, with major gains to present readings since the 1950s. Atmospheric concentrations of carbon dioxide gas are now at historic high levels causing grave concern regarding future temperature rises.

Among other agricultural industries, the production of grapes and wine is known to be very climate sensitive, as evidenced by the specialisation of grapevine cultivars and wine styles in many of the world's wine regions. An early report to OIV by the senior author R. Smart [1] predicted climate change impact on grape and wine production. These effects are now being reported in many countries, for example with timing of grapevine phenology and changes in grape composition and wine style and quality [2-5].

Wine region definition in Australia is characterised by the Geographical Indication System for which temperature suitability was recently reviewed [6]. This study demonstrated a significant temporal increase in the Growing Season Temperature (GST) index over the vast 15-20 years, challenging the selection of a period which represents 'average' conditions. The inclusion of a further region of increased temperature labelled 'hot' was necessary. While the wine sector has become more aware of the implications of climate change over the last two decades, early responses were for adaptation, especially of regional variety although even this strategy proceeds slowly. Analyses of Australia's varietal plantings illustrate more tendency toward so-called "international varieties" than those suited to warmer growing conditions [7]. Management changes by producers to mitigate carbon emissions have been even slower to be adopted. However, the wine sectors of both Australia and New Zealand have recently and independently announced goals to become carbon neutral by 2050, and this contribution supports this intention.

2 Carbon footprint of wine

Our paper is based on the Australian Wine Research Institute cradle to grave carbon footprint analysis [8]. This analysis identifies that transport, packaging, and remote bottling were "hot spots", accounting for 68% of the emissions in the average life-cycle. Grape and wine production contributed 15% and 17% respectively, which is relatively small compared to glass and transport. Data extracted from this paper are presented in Tables 1 and 2.

Table 1. Contributions to emissions from vineyards from Fig. 3 [8].

VINEYARD	Greenhouse gas emissions (kg CO2e/L)	%
Diesel	0.0648	40.5
Electricity	0.0426	26.6
Irrigation	0.0310	19.4
Fertiliser	0.0088	5.5
Grape transport	0.0056	3.5
Agrochemicals	0.0037	2.3
N2O emissions	0.0037	2.2
TOTAL	**0.1602**	**100.0**

Table 2. Contributions to emissions from wineries from Fig. 3 [8].

WINERY	Greenhouse gas emissions (kg CO2e/L)	%
Electricity	0.1588	81.5
Citric acid	0.0102	5.2
LPG	0.0079	4.0
Refrigerants	0.0051	2.6
Dry ice	0.0046	2.4
Wastewater	0.0046	2.4
Caustic	0.0037	1.9
TOTAL	**0.01949**	**100.0**

3 Reducing carbon footprint in the vineyard

According to Abbott et al [8], the use of diesel by machinery in vineyards is a major component of emissions at 40%, equating to more than $50M AUD in annual Australian vineyard vehicle fuel costs based on current Australian National Greenhouse Accounts emission factors, and assuming a very conservative diesel fuel price of $1.50 per L (AUD). Considered on a national basis, this suggests significant scope to consider investment in the development of low emissions diesel alternatives such as battery and hydrogen electric vineyard vehicles. Both battery storage and hydrogen fuel cells have their own inherent advantages and disadvantages: batteries offer high efficiency for both storage and electrical conversion (80-95%) however suffer from low energy density (0.13 kWh/kg compared with 12.7 kWh/kg for diesel), while hydrogen offers superior energy density (39 kWh/kg) albeit at a lower conversion efficiency (60% is typical) [9]. While presently far from common place in Australia, such electric vehicles and machinery are now coming onto the market and are already an option for vineyard emissions mitigation where suitable charging infrastructure is already in place [10]. We note however that the capital costs of change especially within a short period can be a significant barrier to adoption. The means by which hydrogen is obtained is also significant with respect to carbon intensity. Hydrogen produced via electrolysis of water using renewable electricity is the most climate friendly compared with hydrogen obtained from natural gas (with or without carbon capture) [11] or as a by-product of Fischer-Tropsch diesel synthesis from coal – the latter being particularly carbon intense as diesel produced from coal has 150% more embodied carbon than conventional diesel production from fossil fuel crude oil [12].

The use of electricity by vineyard owners including for pumping irrigation water is another major emission at just over 26%, followed by emissions associated with delivery of irrigation water by third-party suppliers at just under 20%. In 2021, 67.5% of Australia's electricity was supplied by fossil fuels, with the remaining 32.5% supplied by renewable sources (comprising of wind, hydro, solar and bioenergy) [13]. Replacing grid-sourced electricity with renewables will have therefore major impact on the vineyard (and winery) carbon footprint, and in typically sunny Australia, conversion from grid electricity to battery power supplied by renewable sources such as solar for irrigation pumping is economical and becoming more commonplace, with renewable bioenergy derived electricity also an emerging option.

Regarding vineyard bioenergy conversion, vineyard prunings are an obvious feedstock candidate. Comprising around 20% of crop weight, their collection can be readily mechanised for later processing. Mobile in-field pyrolysis and gasification units are now available which can convert waste organic biomass into biochar and electricity respectively, for subsequent application to vineyard soils (in the case of pyrolysis derived biochar) or battery storage (in the case of gasification). Vineyard derived biochar has

shown to offer several benefits, not only as a means of carbon sequestration [14] but as a soil amendment to increase water retention as well as available nutrients for plant growth [15]. Pyrolysis also produces liquid products from the condensation of vapours from the pyrolysis process [16]. Referred to as bio-oil, with further processing these have potential to substitute for fuel oils such as diesel with some caveats: bio-oils have inferior heating values compared with hydrocarbon alternatives and when tested as transport fuels have been associated with poor engine wear, carbon and heavy wax deposition and fuel instability. Jahirul et al [16] propose that these issues may be overcome with improvements to pyrolysis processing and engine components, suggesting that bio-liquids (like other technologies discussed herein) are not a direct swap for conventional technology, and that further capital investment, equipment modifications and field testing would be required.

Fertiliser is a minor item contributing to vineyard emissions. Nitrogen fertiliser at least may be replaced by mid-row growth of legumes, also solar-powered!

4 Reducing carbon footprint in the winery

In wineries, the overwhelming source of CO_2 emissions is the use of grid electricity at 82%, mostly for refrigeration and air-conditioning as well as driving other winery equipment. Improvements to the process efficiency of these activities can be readily achieved in the short term (for example by improving thermal insulation and review of wine/brine and space cooling temperature set points) which will lower energy demand with a commensurate reduction in carbon emissions intensity. Such improvements can often be readily implemented, with favourable return on investment [17] as well as carbon mitigation [14].

Looking beyond the short-term opportunities for demand reduction, there remains a need to identify strategies that can satisfy the residual demand with renewable carbon friendly sources of energy. As for vineyards, conversion to solar energy is one such strategy, which is being adopted by Australian wineries. Biomass energy is another.

Wineries generate significant quantities of organic biomass waste including grape marc, stalks, and wastewater sludge. Existing disposal options for marc include composting for mulch or further processing to extract higher value end products including beverage spirits and tartaric acid [18]. However, an alternative use (that is arguably far more compelling given the urgency of carbon mitigation) would be to instead utilise these as feedstocks for bioenergy production. As with vineyard prunings, thermal processing strategies such as combustion/gasification and pyrolysis could be considered (producing electricity and biochar respectively), as well as biological treatment processes such as anaerobic digestion to produce biogas (for subsequent conversion to electricity). These bio-treatment processes are mature and well established in a variety of agricultural sectors [17] (and in the case of anaerobic digestion, within the wine sector itself for treatment of winery wastewater), and could be adapted to support winery electricity needs. Development of a regional processing facility could be considered in locations where capital costs for such infrastructure are prohibitive for a single producer.

In terms of winery carbon mitigation, significant opportunity may be found at the heart of the winemaking process itself: alcoholic fermentation. Wine fermentation results in carbon dioxide emissions of approximately 56 L CO2 per litre of wine [19], which is equivalent to 0.11 kg CO2e/L. Ordinarily in carbon accounting these fugitive emissions are considered "biogenic emissions" and part of the "short-term carbon cycle", meaning that they are assumed to be "in balance" with vineyard sequestration and therefore do not contribute to the cradle-to-grave carbon footprint. There is some debate as to whether this the largest Scope 1 emission of wineries should be ignored [20]. However, regardless of the merits of the biogenic approach to carbon accounting, the emissions (short-term they may be) are clearly substantial relative to other activities across the supply chain: 0.11 kg CO2e/L is equivalent to 9.5% of the overall cradle-to-grave carbon footprint for wine, and more than 56% of winery CO2e emissions. Put another way, if these fermentation emissions were captured and sequestered it would result in a 9.5% reduction in carbon emissions associated with Australian domestic bottled wine; (that's more than half of the emissions associated with winemaking or nearly two-thirds the emissions associated with vineyards). So, notwithstanding the debate on whether biogenic emissions should be included within wine LCA, sequestration of fermentation emissions present a significant mitigation opportunity.

5 Reducing carbon footprint in packaging and transport

Undoubtedly glass bottles are the "elephant in the room" with respect to the carbon footprint of wine. This arises from high energy contents for manufacture though less for recycling, and high transport costs. When faced with a modern climate crisis, the industry should question reasons for maintaining the devotion to a package designed over 390 years before, the glass bottle. Among packages to be found in supermarkets, the glass wine bottles sets unfortunate records for weight and volume inefficiencies, since their weight and unfortunate shape result in inflated transport costs, The present alternate wine packages including plastic sacks and pouches, cans, cardboard cartons, PET bottles etc can present their own recyclability issues, but invariably have a greatly reduced carbon footprint. What is certain that wine purchases are typically for present consumption rather than storage [21], and that packaging recyclability is an emerging issue in general in society.

Might wine consumers be convinced to "*give up the bottle*" because of their environmental concerns; this issue will become a major conversation piece, and one hopefully to be taken up by wine journalists and consumers alike. This issue will become the primary one facing the global wine sector over the next two to three decades, as society

struggles to contain carbon emissions to limit temperature increases to less than 2ºC. Studies of consumer acceptance of alternate packaging will be pivotal for many products in many markets, as will be the actions (or reactions) of glass manufacturers and distributors, and the wine retail sector.

Grape and wine producers and many in the supply chain are taking the initiative for carbon emission reduction, and for Australia at least the retail sector has not become much involved. In the instance of replacing the glass wine bottle, the retail sector has a particular role, to interact with wine consumers about the cause of mitigating climate change. In-store information could promote sustainability and the particular threat of glass packaging, and help promote alternatives. Retail stores are in a unique position to intervene by introducing policies to either "replace" by encouraging alternate packaging; to "reuse" by encouraging in-store refills, and or to encourage "recycle". For the latter operation retail outlets could become centres for glass return to recycle rather than leaving the task to municipal waste removal of known low efficiency. Similar remarks can be made for winery cellar door outlets, and winery tourism has a special role to play in reducing the carbon footprint of wine sales [22,23]. A simple initiative is to provide electric-fuelling points for vehicles.

6 Achieving carbon neutrality

The Australian wine industry has recently engaged support to "road map" actions to achieve carbon neutrality, and this process is defining goals which are both easier and more difficult to achieve. Among the easier target actions are included replacing grid electricity for both vineyards and wineries. In general Australia is fortunate in its sunny climate, and conversion to renewable solar energy is common as well as cost effective in very many locations.

There are however also "roadblocks" which may make transition to a carbon neutral production very difficult. Foremost among these is the use of fossil fuel derived diesel for vineyard machinery power, accounting for the major emission at 40% of the vineyard total. Achieving alternate packaging will also be a major obstacle, given the present widespread use of inefficient glass bottles. Many alternate packages are presently available most of which offer carbon emission reductions in manufacture and transport and good recyclability. An outstanding area requiring research is into consumer appeal, and indeed as to whether consumers may be encouraged to change their packaging preference for environmental reasons.

The carbon footprint reduction concept is not always well understood at present although there is good awareness of climate change issues. Part of this confusion arises from confusing terminology in the public domain. Consider terms like sustainable, organic, biodynamic, regenerative, eco-friendly, carbon neutral, carbon compensated etc. How do these terms relate to avoiding the climate crisis? Some of these other management systems for vineyards, for example 'organic' and 'biodynamic', actually increase emissions by requiring more tractor passes and so diesel fuel.

In the short term, not all emissions may be eliminated, and this leads to the concept of purchasing carbon offsets or credits. There are national and international markets for carbon offsets, which vary considerably in price. Some proposals for carbon neutrality can rely excessively on offsets rather than change management practices, a process often called "green washing".

7 Conclusion

The industry ambition to carbon neutrality by 2050 is coordinated by Sustainable Winegrowing Australia (https://sustainablewinegrowing.com.au), a program conducted from the Australian Wine Research Institute on behalf of two national bodies Australian Grape and Wine and Wine Australia. Sustainable Winegrowing Australia is a voluntary program offering accreditation designed to suit the changing needs of all Australian grape and wine producers. Membership is currently limited but growing.

As part of a national mitigation strategy, producers will realise that not all changes will necessarily be economical in the short term or perhaps even in the longer term. However, for an industry which is so climate sensitive, there is an element of ethics involved in decisions to mitigate as part of a society effort. We hear of these sentiments in other sectors, increasingly from an investor angle, and from supermarket supplier and customer perspective, but why is so little made of the ethical issue for wine. Many wineries fighting climate change are energising their employees and their families with this approach. However wine journalists are surprisingly quiet about encouraging consumers to take an interest in the mitigation issue, how else might they be energised? As for input from the retail sector there seems to be virtually none, do you recall seeing any in store information, or is it hidden behind the bottles? In fact, *we are all in this together*, we have an abiding common interest in overcoming climate change.

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