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AWRI Australian Wine Research Institute

Affinity Labs

LIFE CYCLE ASSESSMENT (LCA) OF AUSTRALIAN WINE INDUSTRY



FINAL REPORT TO WINE AUSTRALIA

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Abstract

An update of the 2016 Australian wine industry life cycle assessment was undertaken in line with current international standards and best practice. The analysis showed that the indicative cradle-to-grave carbon footprint of Australian still wine is 1.05 kg CO2e per L.

Several hotspots were identified that contributed significantly to the greenhouse gas emissions of the product including glass packaging, winery electricity, vineyard diesel use and product distribution. Several strategies were discussed to help reduce these emissions, including further light weighting of bottles, shifting to alternative packing and distribution to export markets in bulk.

The results obtained in this study represent a 10% reduction in emissions for Australian wine comparative to the 2016 study undertaken by the AWRI (1.16kg CO_2e/L). The most significant change between the two models is the penetration of renewable energy sources impacting upon the Australian state and country electricity mix. Increases in the proportions of bulk wine export and glass recycling rate increases within export and domestic markets further drove emissions reductions.

Executive Summary

A sector level LCA of the Australian wine industry was undertaken by the Australian Wine Research Institute in 2016. Since then, the science and practice of LCA has advanced and the Australian wine sector continues to progress and evolve with domestic and global challenges and successes. This project aims to update the 2016 Australian wine industry LCA in line with current international standards and best practice, to see how sector level changes have influenced the greenhouse gas emissions of Australian wine production and distribution.

The LCA drew on data from Sustainable Winegrowing Australia, as well as data from peak bodies within the wine industry, both nationally and internationally. Further supporting data was provided through Australian and globally recognised energy, transport and agriculture databases to ensure emission models and data quality was at a high level to facilitate the outcomes.

The analysis showed that indicative cradle to grave carbon footprint of Australian Wine was 1.05 kg CO2e per L. Several hotspots were identified that contributed significantly to the greenhouse gas emissions of the product including glass packaging, winery electricity, vineyard diesel use and product distribution. Several strategies were discussed to help reduce these emissions, including further light weighting of bottles, shifting to alternative packing and distribution to export markets in bulk.

The results obtained in this study represent a 10% reduction in emissions for Australian wine comparative to the 2016 study undertaken by the AWRI (1.16kg CO_2e/L). The most significant change between the two models is the penetration of renewable energy sources impacting upon the Australian state and country electricity shift. Increases in the proportions of bulk wine export and the glass recycling rate increases within export and domestic markets further drove emissions reductions.

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Abbreviations

ABS	Australian Bureau of Statistics
AI	Active Ingredient
ALCAS	The Australian Life Cycle Assessment Society
AusLCI	Australian Life Cycle Inventory Database Initiative
AWRI	Australian Wine Research Institute
BOM	Bureau of Meteorology
CH_4	Methane
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalent
ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
kg	Kilogram
L	Litre
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MJ	Mega joule
N_2O	Nitrous oxide
NGA	Australian National Greenhouse Accounts
PMS	Potassium metabisulfite
SWA	Sustainable Winegrowing Australia
t	Tonne
UAN	Urea and ammonium nitrate fertiliser

Preface

Wine Australia commissioned the Australian Wine Research Institute and Affinity Labs to perform an update of the Life Cycle Analysis (LCA) of the Australian Wine Industry, comparing results of the 2016 study as summarised within Abbott et al. published in the Wine and Viticulture Journal (31(1): 35-37). The update includes the revision of data used to undertake the previous assessment, drawing on the increasing data acquired through Sustainable Winegrowing Australia (SWA), as well as newly updated Global and Australian specific LCA data and data tools. The update to the existing LCA model was guided by current best practice standards as outlined in recent regulation changes, including International standards ISO 14040 (Environmental management – Life cycle assessment – Principles and Framework) and ISO 14044 (Environmental management – Life cycle assessment – Requirements and guidelines). The updated LCA focused on the assessment of carbon emissions as contributed by the Australian Wine Industry, assessing the primary sections of the industry including grapegrowing, winemaking, packaging and distribution. SimaPro 9.4.0.1 (Pré Consultants, Netherlands) LCA software was used in conjunction with Microsoft Excel for data analysis. An attributional life cycle model was followed for the sector.

This report has been written covering the core elements of the modelling, specific to:

- Grape growing (Section 3)
- Winemaking (Section 4)
- Packaging (Section 5)
- Distribution (Section 5)

The common goals and scope of the study are described in Sections 1 and 2 and overall conclusions and recommendations are provided in Section 6.

1. Goal

1.1 Reasons for the study

Wine Australia commissioned Affinity Labs of the Australian Wine Research Institute (AWRI) to undertake an update to the 2016 LCA developed as summarised within Abbott et al (2016). The update includes the revision of data used to undertake the previous assessment, drawing on the increasing data acquired through Sustainable Winegrowing Australia, as well as newly updated Global and Australian specific LCA data and data tools. The repeat analysis aimed to understand whether the industry emissions dials had shifted in the six years since the first assessment undertaken.

1.2 Intended applications and target audience

The intended applications of this study are:

- To provide information to the Australian grape and wine sector on where in the supply chain greenhouse gas emissions, and other relevant impacts occur, and therefore where the biggest opportunities for emissions reductions and improvement lie within the sector.
- To provide information on the influence of different production practices on greenhouse gas emissions; and
- To inform the purchase of carbon credits to offset generated carbon emissions and support the application of carbon neutrality for the sector.

This study is not intended to support any comparative product assertions that would be disclosed to the public.

1.3 Review

The assessment undertaken has used primary data extracted from Sustainable Winegrowing Australia (SWA) and other peak bodies within the Australian wine industry and other related industries as referenced throughout the report. The assessment has also used estimates, secondary data and/or relevant literature to define the outcomes in line with the 2016 LCA model. The data within SWA and other data used for the purposes of this assessment have not been independently verified, and hence the results presented cannot be used to make comparative assertions.

2. Scope

2.1. Functional units

The functional unit defines the basis for all results reported in the study. The functional unit is defined as:

- 1 L of wine produced and packaged in the destination market.

The destination market may be domestic or various export markets.

2.2. Impact categories

The impact category used in the study and prescribed methodology are outlined in Table 1. The methodology used is based on the best practice guide for mid-point Life Cycle Impact Assessment (LCIA) in Australia (Renouf et al, 2018).

Global Warming Potentials (GWP) are defined for a 100-year time horizon, following IPCC Forth Assessment Report (IPCC, 2007) and are expressed as kilograms of carbon dioxide equivalents ($kgCO_2$-e).

Table 1: Impact Categories

Impact Category	Unit	Method
Greenhouse Gas Emissions	kg CO_2e	ALCAS Best Practice LCIA Recommendations

The model used to calculate the average carbon footprint for Australian wine draws on the primary production data as extracted from the Sustainable Winegrowing Australia database (discussed section 2.4). Medians for small, medium and large sites were developed from the database outputs to capture scale effects. The model was weighted to represent the incidence of these sized sites throughout the industry in accordance with the National Winegrape Grower Handbook (2013) from the Wine Grape Growers Association (see Appendix A), and recent crush and production figures as referenced through Wine Australia, and the Wine Grape Council of South Australia (WGCSA).

2.3. System boundary

A simplified system boundary diagram for the sector is provided in Figure 1. More detailed system boundary diagrams are provided in each relevant chapter. The grape growing phase included the use (scope 1 and scope 2) and production and transport (scope 3) emissions of all inputs to the process as well as soil emissions from fertiliser use and acidifying emissions from sulfur use. Winemaking includes the emission profiles for onsite electricity use, and combustion of fuels and gases for processing requirements. Estimates from winemaking additives and inputs (e.g. oak), cleaning agents (e.g. citric acid and potassium hydroxide) as well as onsite wastewater treatment, refrigerants, and purchased CO_2 have been included. Primary and secondary packaging has been included, and the various domestic and international sales routes have been modelled using a range of data sources. The disposal and recycling of

packaging materials have been included in the system boundary. The consumer phase has not been included within the modelling.

For inputs produced internationally, emissions from global market processes have primarily been modelled based on data from the Ecoinvent 3.8 database. Emissions from these processes (i.e. emissions attributed to transatlantic shipping, on-road freight in export markets, international road maintenance etc.) include a transport component through the market so only additional transport requirements have been modelled.

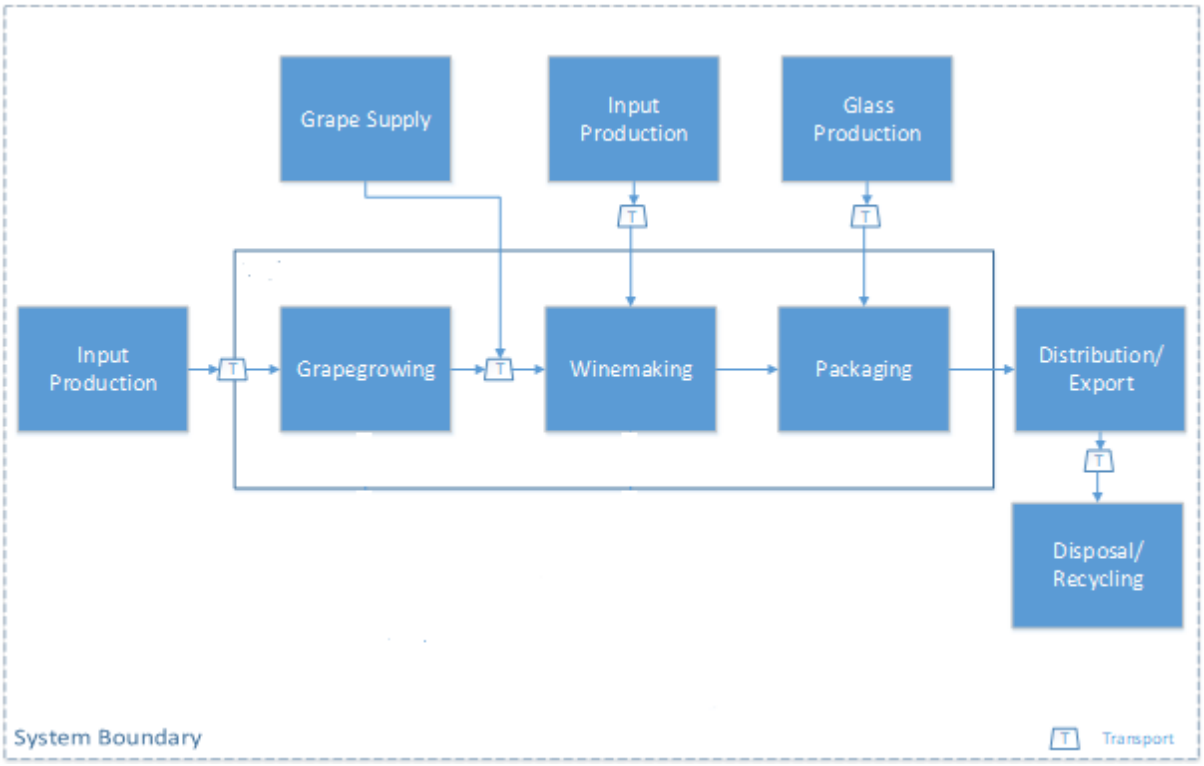


Figure 1: Sector level system boundary

2.4. Data source and Sustainable Winegrowing Australia

The primary data used to construct the LCA was extracted from Sustainable Winegrowing Australia. Sustainable Winegrowing Australia is the Australian wine industry's national sustainability program. The program takes a holistic approach to managing, supporting, and promoting sustainability within the wine industry. Sustainable Winegrowing Australia is modelled on global best practices and aligned to the United Nations Sustainable Development Goals, with progress towards these monitored annually. The program is administered by the Australian Wine Research Institute with governance, endorsement and active support from Australian Grape & Wine and Wine Australia. The program covers the fundamental components of sustainability being environmental, social, and economic and can be applied to both vineyards and wineries. Membership of the program is voluntary, and all members annually provide a set of standard production and resource use data including water, fertiliser, electricity and fuel use, and waste and wastewater generation and recovery (scope 1 and scope 2 emissions).

Sustainable Winegrowing Australia evolved from a predecessor program 'Entwine Australia', which was developed in 2009 by the Winemakers Federation of Australia as

the Australian wine industry's umbrella environmental assurance program, and data from Entwine was used to model the 2016 LCA.

In the past three years the number of members of Sustainable Winegrowing Australia has increased by around 45% representing an increase of more than 10% of the vineyard area covered by the program. This has increased the diversity of vineyard businesses contributing to the dataset for LCA modelling. There has been a smaller increase in coverage of the program by volume of Australian wine production since 2016, however, the increased membership reflects adoption of the program by more small and medium wine producers, hence strengthening the weighting capability across the Australian wine landscape.

Data collected through Entwine in earlier years (2013/14 to 2015/16) was used to prepare the 2016 LCA model (Abbott et al. 2016). The 2016 model included data from members covering 25% of the Australian vineyard area and a quarter of its grape production. This new LCA model, using data from Sustainable Winegrowing Australia, has greater coverage of Australia's vineyard area (38%) and grape production (35%). The winery data used in this LCA represents a similar proportion of the volume of Australian wine production as it did in 2016 (43% versus 44% respectively).

2.5. Time period

The current LCA was conducted on data provided by grape and wine producers through Sustainable Winegrowing Australia across three consecutive financial years (2018/19 to 2020/21). The aggregated annual datasets were combined to remove the seasonal variability effects on grape yield and wine production caused by factors such as frost, disease and bushfires.

2.6. Size Categories

The method for modelling the average carbon footprint for Australian wine draws on the primary production data extracted from the Sustainable Winegrowing Australia database. The model was weighted to represent the incidence of small, medium and large vineyards and wineries across the Australian wine industry in accordance with the National Winegrape Grower Handbook (2013) from the Wine Grape Growers Association (see Appendix A), and recent crush and production figures as referenced through Wine Australia, and WGCSA (Wine Australia 2021, WGCSA 2021). Data collected across the three consecutive financial years (2018/19 to 2020/21) was pooled and the median input values extracted across each category of scope 1 and scope 2 emissions data for small, medium and large sites to capture scale effects.

The size categories used throughout the modelling provided in Table 2 are based on standard guidelines as recognised through Australian Grape and Wine and Wine Australia:

Table 2. Vineyard and winery size categories used for the LCA analysis.

Size Category	Vineyards (ha)	Wineries (t)
Small	< 25	< 2000

Medium	25 – 50	2,000 – 10,000
Large	> 50	> 10,000

For data captured through Sustainable Winegrowing Australia, the median value in each of the scope 1 and scope 2 input categories was taken (i.e. median value across the three consecutive financial years (2018/19 to 2020/21) for diesel use). The median value was chosen as it is the most informative measure of central tendency for skewed distributions or distributions with outliers, which underpins the data driven by producers inputs.

Previous assessments have looked to disaggregate the data from Sustainable Winegrowing Australia, and from these it has been advised that disaggregation based on size was the best option over region. Previous trials noted that the range of variation between size categories was much smaller than the range of variation between regions hence this approach was followed.

The distribution of member data used across each vineyard size category is shown in Figure 3 and the GI zone of the members distribution is shown in Figure 4.

The members array and data collected from Sustainable Winegrowing Australia as represented by size for wineries is shown in Figure 5.

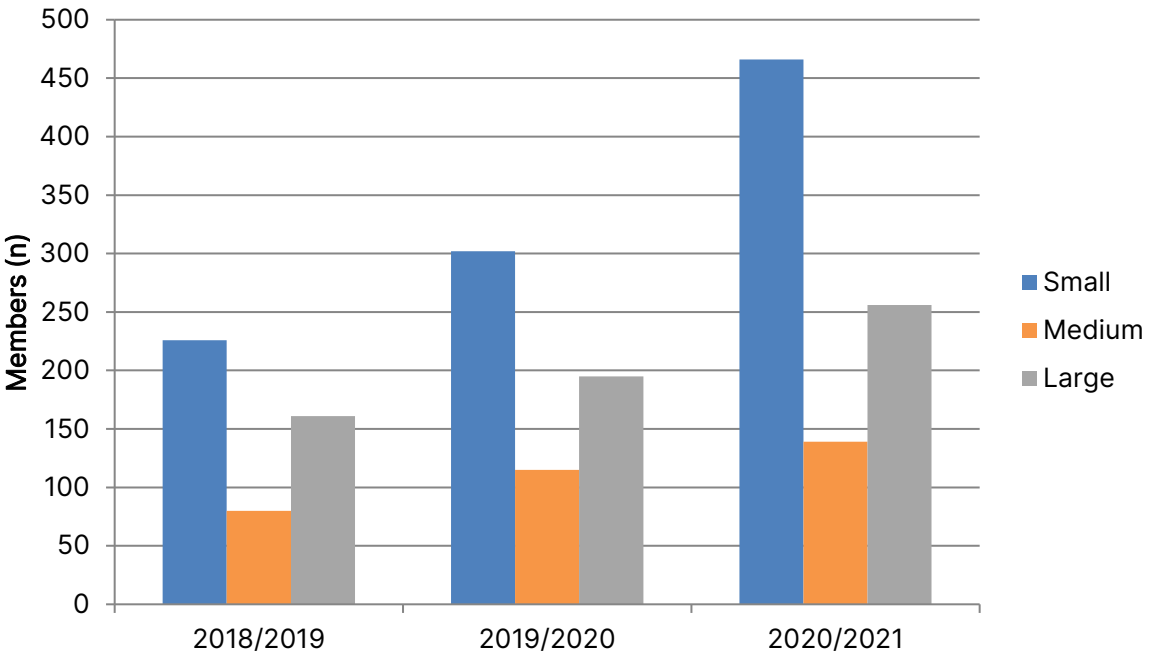


Figure 3. Distribution of Sustainable Winegrowing Australia vineyard members across small, medium and large categories.

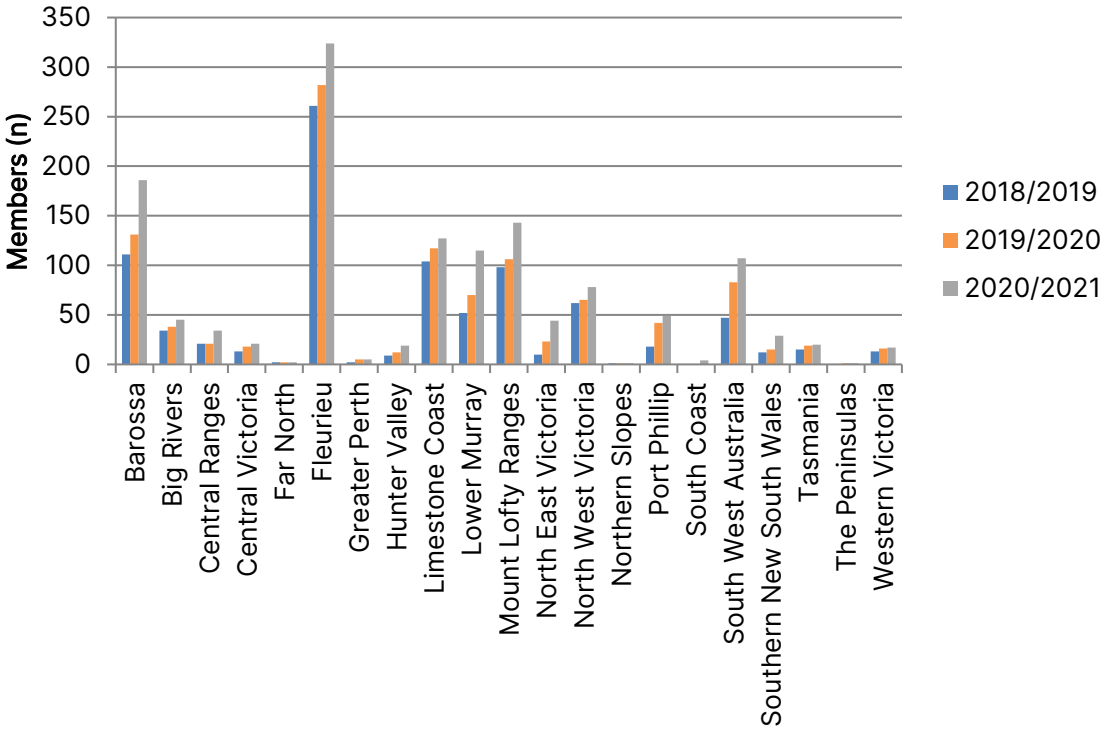


Figure 4: Distribution of Sustainable Winegrowing Australia vineyard members by GI zone.

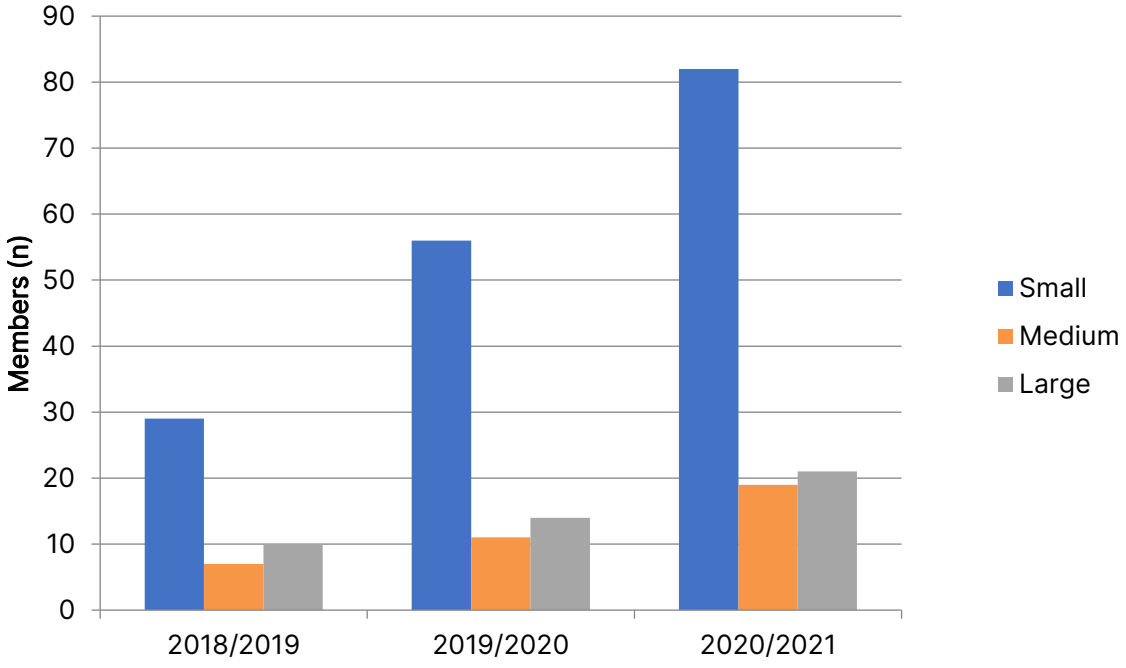


Figure 5: Distribution of Sustainable Winegrowing Australia winery members based on size.

2.7. Data sources

Primary data used for the life cycle analysis was aggregated and extracted from Sustainable Winegrowing Australia.

A series of the input materials and processes not prescribed within the data captured through Sustainable Winegrowing Australia (discussed in respective sections) were extracted and used from additional databases as follows:

- Ecoinvent 3.8 data as unit processes and system processes, with links to other processes. Compiled November 2021 - see section 2.7.1.
- AusLCI database (Version 1.39 23 July 2022) - see section 2.7.2.
- Agri-footprint version 6 (June 2022) – as unit processes and system processes with links to other processes - see section 2.7.3.

Industry-specific data was utilised in addition to the above primary data. The details of these are listed in Table 3. Data usage has been linked directly to the sector level area where the data was used to infer upstream, or downstream processes and other data is discussed in the inventories within each section throughout the report.

Table 3: Data sources used to validate and support the development of the Life Cycle Analysis.

Data Use	Source (see Section 9 for detailed reference list)
Winegrape Crush (t)	**Wine Australia** National Vintage Report (2019, 2020, 2021) **WGGA** National Winegrape Grower Handbook (2013) **WGCSA** SA Winegrape Crush Survey (2019, 2020, 2021) **Winetitles** The Australian and New Zealand Wine Industry Directory (2021, 2022) **Australian Bureau of Statistics (ABS)** Agricultural Commodities -Australia, states and territories and ASGS regions – 2020-21
Wine production (kL)	**Wine Australia** Australian Wine: Production, Sales and Inventory Reports 2018/19, 2019/20, 2020/21 **WGGA** National Winegrape Grower Handbook (2013) **WGCSA** SA Winegrape Crush Survey 2018/19, 2019/20, 2020/21
Vineyard area (ha)	**Wine Australia** National Vineyard Scan (2019) **WGGA** National Winegrape Grower Handbook (2013) **WGCSA** SA Winegrape Crush Survey (2018/19, 2019/20, 2020/21) **Australian Bureau of Statistics (ABS)**

	Agricultural Commodities–Australia, states and territories and ASGS regions–2020-21 **Winetitles** The Australian and New Zealand Wine Industry Directory (2021, 2022)
Australian Wine Exports	**Wine Australia** Australian Wine: Production, Sales and Inventory Reports 2018/19, 2019/20, 2020/21 **Wine Australia** Export Market Dashboard (2021, 2022) https://marketexplorer.wineaustralia.com/export-dashboard **Google Maps** Transport routes in export countries (https://www.google.com/maps) **SeaRates** https://www.searates.com/ (2022)
Australian Wine Domestic Sales	**Wine Australia** Australian Wine: Production, Sales and Inventory Reports 2018/19, 2019/20, 2020/21 **Australian Bureau of Statistics (ABS)** Shipments of Wine and Brandy in Australia by Australian Winemakers and Importers (2014)
Irrigation and water sources	**Australian Bureau of Statistics (ABS)** Water Use On Farms–Australia, states and territories and ASGS regions–2020-21 **Bureau of Meteorology (BOM)** Water Information Dashboard (http://www.bom.gov.au/water/dashboards) National Water Account (http://www.bom.gov.au/water/nwa/2020/index.shtml) **Murray Darling Basin Authority** Water Take Reports under the Basin Plan sustainable diversion limits | Murray-Darling Basin Authority (mdba.gov.au)
Glass production	**The European Container Glass Association (FEVE)** Engagement to determine recycling rate of glass in European market. **Owens-Illinois, Inc (O-I) (2010)**
Agrochemicals / Spray Diaries	**GrapeWeb (AgSmart Pty Ltd 2022)**

2.7.1 Ecoinvent Database

The ecoinvent v3 database contains Life Cycle Inventory (LCI) data from various sectors including energy production, transport, building materials, production of chemicals, metal production and fruit and vegetables. The database consists of over 20,000 interlinked datasets, each of which describes a life cycle inventory on a process level. SimaPro provides six libraries that each contain all the processes in the ecoinvent database but use different system models and contain either unit or system processes.

2.7.2 AusLCI Database

AusLCI database is a National LCI database developed by the Australian Life Cycle Assessment Society (ALCAS). AusLCI provides and maintains a national, publicly accessible database with easy access to authoritative, comprehensive, and transparent environmental information on a wide range of Australian products and services over their entire life cycle. It is an invaluable tool for those involved in environmental assessment and particularly life cycle assessment (LCA), as it provides consistent guidelines, principles, and methodologies for the collection of LCI data, along with protocols for LCA processes for different sectors. The data presented in AusLCI is provided by data suppliers with no warranties as to its accuracy or correctness. Data contained in AusLCI covers individual unit processes, or cradle-to-gate processes where indicated, but not full life cycle data.

2.7.3 Agri-footprint Database

Agri-footprint includes process inventories of crop cultivation, crop processing, animal production systems and processing of animal products for multi-impact life cycle assessments. Agri-footprint also contains inventory data on transport, fertilizers production and auxiliary materials. Agri-footprint is available in three different libraries, based on mass, energy or economic allocation.

3. Grape growing

3.1. Background

Grapevines and winegrape production are a perennial cropping system, best suited to the temperate regions of Australia. Grapevines take three to five years to establish but can continue bearing fruit for decades afterwards. The oldest vines in Australia are over 170 years old (Langmeil, 2016). New plantings have all but ceased in Australia in recent years, with the only plantings occurring to replace old vines, often as the result of disease or to replace with new varieties (Wine Industry Directory, 2022).

The growing season commences in spring during which time the predominant vineyard activities include irrigation, nutrition management and pest and disease control. Harvest occurs in summer and autumn and, depending on the region and/or end use of the grapes. Harvest may be achieved either mechanically or by hand. Harvested grapes are transported to the winery for processing. After harvest, grapevines enter a period of dormancy in winter during which time the vines are pruned either by hand or machine.

Australian Winegrape production during the period examined in this LCA study is summarised in Table 4.

Table 4: Australian wine grape area and production (Wine Australia 2021, Winetitles 2022)

Year	Production	
	Vineyard area ('000 ha)	Crush (kt)
2018-19	146	1,714
2019-20	146	1,544
2020-21	146	2,028

3.2. System boundary

The system boundary for grape growing (Figure 6) includes the production of all major vineyard inputs including fuels, electricity, agrochemicals, and fertilisers, as well as the delivery of irrigation water (i.e. scope 3 emissions). Processed wastewater is also fed back to the grape growing stage from the winery. All major on-farm activities including spraying, slashing, spreading, pruning, seeding cover crops, irrigating, and harvesting have been captured within the vineyard's diesel use. Soil emissions of nitrous oxide, nitric oxide and ammonia have been modelled.

Changes in soil carbon from direct land use change are within the system boundary; however, new plantings have all but ceased in the wine industry and are limited to replanting old vines no longer suitable for production (Winetitles 2022). No evidence of direct land use change was found to model.

Storage of carbon in the vines, and the production of farm equipment like tractors have not been included.

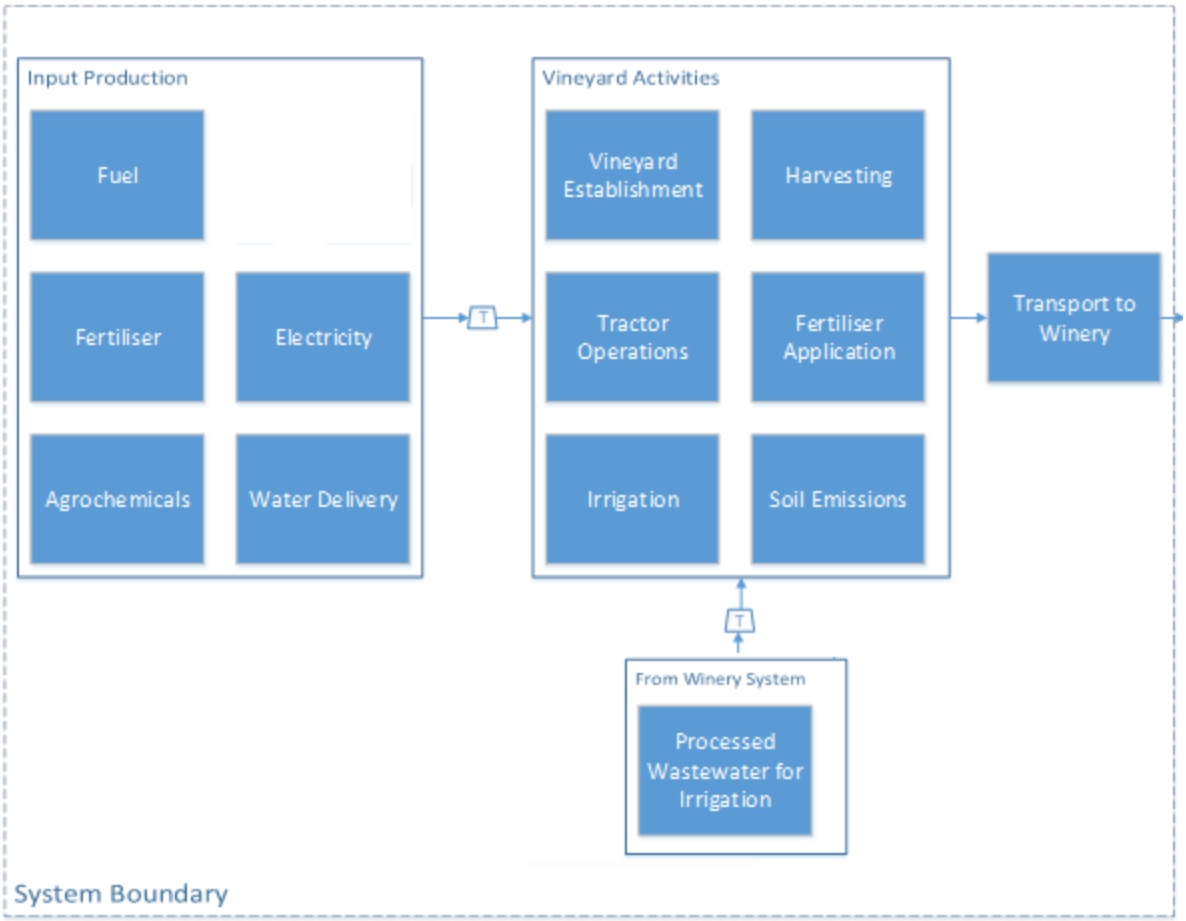


Figure 6: Grapegrowing system boundary

3.3. Modelling Methodology

The life cycle inventory was constructed using Simapro 9.4.0.1 software (Pré Consultants, 2022). A series of the input materials and processes were present in the AusLCI, Agri-Footprint or Ecoinvent 3.8 databases and were used directly. These input materials and processes are noted in the LCI where used. Other processes required more detailed modelling or require some explanation and are described in the following sections.

3.3.1. Size and state weighted grower data

To define the weighting categories for grape growing data, both by size and by state, the National Winegrape Grower Handbook (2013) from the Wine Grape Growers Association (see Appendix A), and recent crush and production figures as referenced through Wine Australia, and WGCSA were used. Comparisons were further drawn against the National Vineyard Scan (Wine Australia 2019). Figure 7 defined a schematic extracted from the National Vineyard Scan (Wine Australia 2019) which highlights vineyard area by state within Australia. The WGGA table profiling regional grower profiles by grower type and vineyard size, correlating with winemaking tonnes produced is available in Appendix A. Yield estimates were compared based on SWA and WGGA data for each of small, medium and large sites. The state and sized based weighting categories which further defined allocation for electricity split on a national scale are defined as per Table 5 below:

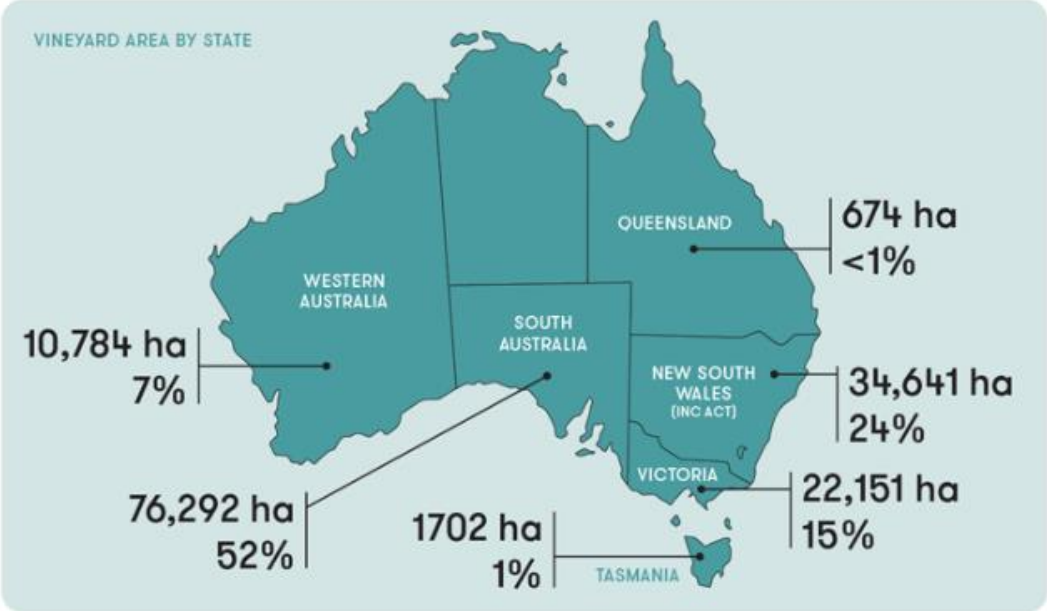


Figure 7: Australia's National Vineyard Scan (Wine Australia 2019)

Table 5: State and size weighted grower contribution based on crush.

State	Vineyard Production Weighting		
	Small	Medium	Large
South Australia	55.2%	55.6%	44.2%
New South Wales	17.2%	23.4%	35.3%
Victoria	21.0%	17.1%	16.3%
Western Australia	5.7%	3.7%	3.9%
Tasmania	0.6%	0.1%	0.3%
Queensland	0.2%	0.1%	0.0%
Australian Capital Territory	0.0%	0.0%	0.0%
Contribution to total crush (%)	**23.5%**	**16.1%**	**60.4%**

3.3.2. Electricity mix

The source of electricity for each Australian state in 2022 is provided in Table 6 below:

Table 6: Australian State, Territory and national electricity sources (by percentage) in 2022 (AusLCI 2022).

Electricity Source	NSW	VIC	QLD	WA	SA	TAS	NT	AUS
Coal	69.7	63.0	65.1	21.8	0.0	0.0	0.0	51.4
Natural gas	2.8	3.2	14.2	57.2	33.8	1.0	84.2	17.8
Oil	0.5	0.3	1.5	5.6	1.0	0.2	10.2	1.8
Hydro	4.0	5.5	1.5	0.3	0.0	80.6	0.0	6.1
Other renewables	23.0	27.9	17.6	15.1	65.2	18.2	5.6	22.9

For upstream processes where the electricity source is not necessarily known, the average Australian electricity mix (Table 6) was used and applied in the model.

3.3.2.1. Changes in Australian electricity sources 2016 to 2022

A key observation highlighted between the 2016 (Abbott et al.) and current LCA, is the change in sources of electricity by state. During this time there has been a significant increase in the proportion of renewable energy across all states from 2016 (Figure 8) to 2022 (Figure 9). South Australia, the largest state producer of grapes and wine has increased its renewable energy contribution by 18% across the last 6 years. Victoria, New South Wales, and Western Australia have also increased their renewables penetration by 17%, 14%, and 18% respectively.

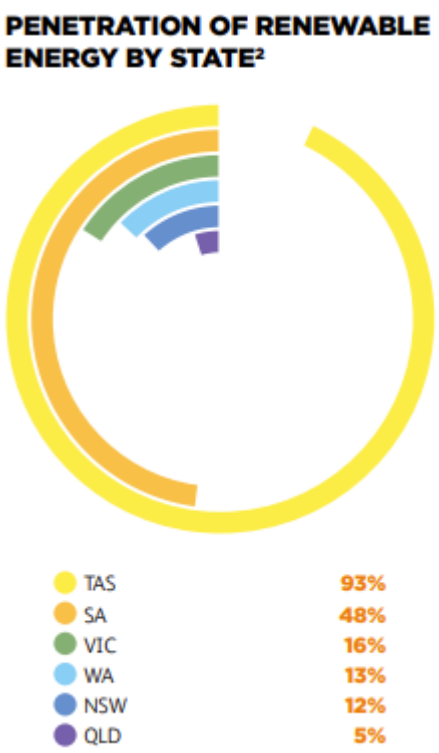


Figure 8: Renewable energy penetration by state as a proportion of generation in 2016 (Clean Energy Council 2016).

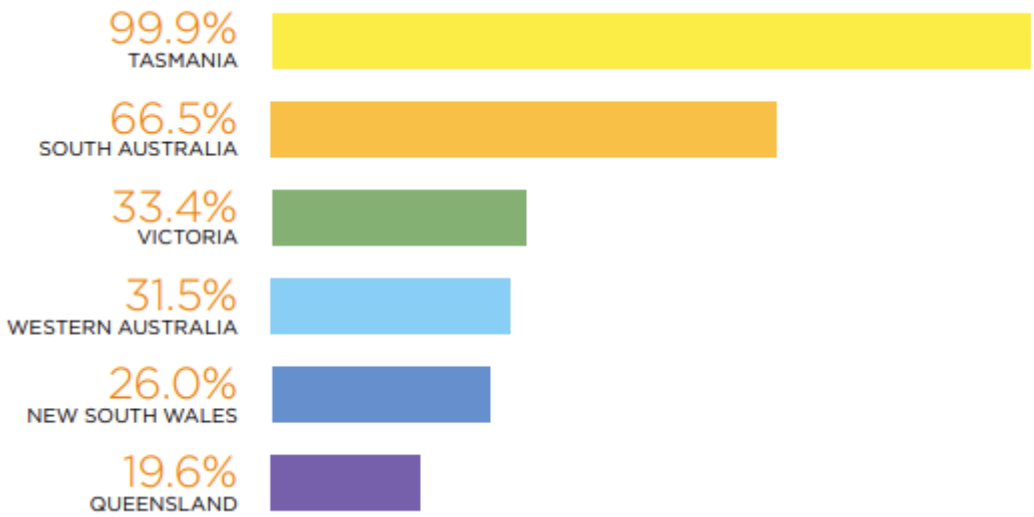


Figure 9. Renewable energy penetration by state as a proportion of generation in 2022 (Clean Energy Council 2022).

3.3.3. Nitrogen and greenhouse gas emissions from soil

The nitrogen cycle is a natural process that occurs in soils and waterways. Nitrogen is present in various forms and changes type depending on its environment. Nitrogen added to the vineyard through synthetic and organic fertilisers increases the nitrogen available to the vines, but also to the other processes in the natural cycle.

A small portion of the nitrogen in the system is converted by microbes into nitrous oxide and released into the atmosphere. Nitrous oxide, while only released in small amounts, is a potent greenhouse gas with a global warming potential 265 times that of carbon dioxide (Clean Energy Regulator 2022). Nitrogen is also released from the soil in the form of other nitrogen gases: ammonia and nitric oxide. A portion of these releases are redeposited back into the soil and this is known as atmospheric deposition. This adds more nitrogen to the system and increases nitrous oxide release. All of these interactions are important when considering the environmental impacts of farming activities.

3.4.2.1 Direct fertiliser emissions

Nitrous oxide, ammonia, nitric oxide and carbon dioxide are all emitted as a direct result of fertiliser application. Nitrous oxide and carbon dioxide are relevant to the greenhouse gas emissions.

In this study, nitrous oxide emissions from applied fertilisers were calculated according to the methods outlined in the Australian National Greenhouse Accounts methodology (Department of the Environment 2021).

Nitrous oxide emissions were calculated according to equation 3.1.

$$E = M \times EF_i \times C \tag{3.1}$$

Where, E is the emissions of nitrous oxide (kg)

M is the mass of nitrogen applied to the vineyard (kg)

EF_i is the emission factor appropriate for the scenario (kg N_2O-N/kg N)

C = 44/28 to convert N_2O-N to N_2O

Carbon dioxide emissions are the result of the hydrolysis of urea and were calculated according to equation 3.2 (Department of the Environment 2021a). Ammonia emissions are also the result of urea hydrolysis; however, these are separately accounted for.

$$E = M \times EF \times C \tag{3.2}$$

Where, E is the emissions of CO_2 (kg)

M is the mass of urea applied to the vineyard (kg)

EF_i is the default emission factor for nitric oxide, 0.2 kg CO_2-C/kg Urea

C = 44/12 to convert CO_2-C to CO_2

3.4.2.2 Crop residues

Cover cropping, or crop residue incorporation in a vineyard is a common practice used to increase carbon or other organic matter stocks within the soil. This process has been

correlated with a tendency to increase nitrous oxide emissions as attributed through the nitrogen cycle.

Nitrous oxide emissions from crop residues were calculated according to equation 3.3 (Department for the Environment 2021a).

$$E = M \times DM \times N \times EF \times C \quad (3.3)$$

Where,E is the emissions of nitrous oxide (kg)

M is the mass of crop residues per hectare (kg)

DM is the dry matter content of the pruning's (kg DM/kg)

N is the nitrogen content of the pruning's (kg N/kg DM)

EF is the default emission factor for the crop residues, 0.01 kg N_2O-N/kg N

C = 44/28 to convert N_2O-N to N_2O

The average pruning weights (1.2 kg/vine) and nitrogen content of prunings (0.73%) from chardonnay vines reported by Hutton et al (2007) were used to estimate the nitrogen input from crop residues. Standard vineyard spacing of 1600 vines/ha and dry matter content of 35% were assumed. This resulted in nitrous oxide emissions from crop residues averaging 0.077 kg N_2O/ha.

3.3.4. Potassium Metabisulfite

Potassium metabisulfite (PMS) is a preservative which is often added to bins of harvested grapes. Some of the PMS will react with air producing sulfur dioxide gas (SO_2). The amount of SO_2 lost will depend on a number of factors including temperature, wind conditions and the time delay before the grapes are crushed. In this study, a 50% loss factor was used. This was based on discussions with winemakers from various sites who reported that these typical levels of SO_2 in juice after crushing. However, it is also acknowledged that 50% loss is likely to be an overestimate as other pathways for SO_2 loss, e.g. through binding with various compounds in the must. are known to occur.

No process models for the use of PMS in vineyards were available in the databases or within the literature. PMS was instead modelled based on the application of liquid sulfur dioxide (Sulfur dioxide, liquid {RoW}| production | APOS, U), from model source observed in Ecoinvent 3.8.

3.3.5. Agrochemicals

Emissions as attributed to the production of agrochemicals were modelled based on aggregated grower spray data extracted from GrapeWeb (AgSmart Pty Ltd 2022). GrapeWeb, owned by AgSmart Pty Ltd, is an online spray diary which is a repository for agrochemical data representing approximately two thirds of Australia's vineyard area. Agrochemical usage data from 2019 to 2021 was aggregated by state and applied to the grape growing emissions model to infer usage. A list of all agrochemicals applied in each state can be found in 0.

3.3.6. Transport

Transport for all inputs and materials to facilitate the grapegrowing was modelled using fleet trucks with a 28t capacity. The model assumes the truck is loaded to 80% capacity on average. This accounts for the trucks being fully loaded on the initial journey, picking up another load for the return journey some of the time, and backhauling empty pallets and crates. Transport distances were estimated based on average distance from capital city to regions based on state distribution of vineyards (Google Maps, 2022).

Transport of grapes to the winery was modelled assuming an articulated truck loaded to capacity, further simulating the return of empty grape bins to the vineyard. Transport distances were estimated to be 10km one-way for small and medium wineries, with large wineries factoring in grape transport from inland regions to other regions where purchase has been undertaken (i.e., Riverland to Barossa – assumed 15% of fruit).

3.4 Life cycle inventory

3.4.1. Australian Winegrapes by grower size.

Primary data was taken from Sustainable Winegrowing Australia records for vineyard management. Data was collected for three years (from 2018/19 to 2020/21) and a median value was used from the aggregated data. The grape growing average was modelled based on contributions from small, medium and large grower data. The small, medium and large grower data inventories as specified below in Table 7 to Table 9, respectively:

Table 7: Australian Grape Inventory for Small producers (<25ha)

Basis	Unit Process	Database or Substance	Median (per ha)	Units
Grapes	Grape Growing Small	WGGA/WA/SWA	23.5%	% Weighted contribution
Grapes Yield	Grape Growing Small	WGGA/WA/SWA	9.46	t
Inputs				
Petrol	Petrol combustion	SWA	15.04	L
Diesel	Diesel combustion	SWA	131.06	L
Electricity	Electricity, AU mix Vin Small	SWA	478.72	kWh
Irrigation (Small)	Water, groundwater, unspecified (other)	SWA/ABS	0.93	ML
	Water, surface water, river	SWA/ABS	1.80	ML
	Water, surface water, river (losses)	SWA/ABS	0.16	ML
	Electricity AU Mix Irrigation Small		170.60	kWh
Land Use	Occupation, arable lane, unspecified use	Definition	10,000	m2a
Urea	Urea modified	SWA	23.79	kg
Synthetic Nitrogen	Urea ammonium nitrate mix {RoW}| urea ammonium nitrate production | APOS, U	SWA	12.87	kg N
Organic Nitrogen	Organic Nitrogen	SWA	17.91	kg N
PMS	Potassium Metabisulfite	Grower engagement	1.14	kg
Fertilizer Emissions	Fertilizer emissions small	NGA	0.12	kg N2O
Crop Residues	Crop Residues	NGA	0.02	t
Urea Hydrolysis	Urea Hydrolysis	SWA/NGA	23.79	kg Urea
Sprays	Pesticide	GrapeWeb (AgSmart Pty Ltd)	Appendix A	kg
Input transport	Transport, lorry 20-28t, fleet average/CH U AusSD/Link U	WGGA region weighted	50.41	tkm
Grape transport	Transport, articulated truck, >20t, customizable/AU U Grape Bin	WGGA region weighted	199.24	tkm

Table 8: Australian Grape Inventory for medium growers producers (25 - 50ha)

Basis	Unit Process	Database or Substance	Median (per ha)	Units
Grapes	Grape Growing Medium	WGGA/WA/SWA	16.1%	% Weighted contribution
Grapes Yield	Grape Growing Medium	WGGA/WA/SWA	10.94	t
Inputs				
Petrol	Petrol combustion	SWA	7.16	L
Diesel	Diesel combustion	SWA	144.47	L
Electricity	Electricity, AU mix Vin Small	SWA	435.65	kWh
Irrigation (Small)	Water, groundwater, unspecified (other)	SWA/ABS	1.06	ML
	Water, surface water, river	SWA/ABS	2.09	ML
	Water, surface water, river (losses)	SWA/ABS	0.19	ML
	Electricity AU Mix Irrigation Small		197.29	kWh
Land Use	Occupation, arable lane, unspecified use	Definition	11,000	m2a
Urea	Urea modified	SWA	12.88	kg
Synthetic Nitrogen	Urea ammonium nitrate mix {RoW}| urea ammonium nitrate production | APOS, U	SWA	9.20	kg N
Organic Nitrogen	Organic Nitrogen	SWA	7.11	kg N
PMS	Potassium Metabisulfite	Grower engagement	1.31	kg
Fertilizer Emissions	Fertilizer emissions small	NGA	0.066	kg N2O
Crop Residues	Crop Residues	NGA	0.0094	t
Urea Hydrolysis	Urea Hydrolysis	SWA/NGA	12.88	kg Urea
Sprays	Pesticide	GrapeWeb (AgSmart Pty Ltd)	Modelled Appendix A	kg
Input transport	Transport, lorry 20-28t, fleet average/CH U AusSD/Link U	WGGA region weighted	56.09	tkm
Grape transport	Transport, articulated truck, >20t, customizable/AU U Grape Bin	WGGA region weighted	228.8	tkm

Table 9: Australian Grape Inventory for medium growers' producers (>50ha)

Basis	Unit Process	Database or Substance	Median (per ha)	Units
Grapes	Grape Growing Large	WGGA/WA/SWA	60.4%	% Weighted contribution
Grapes Yield	Grape Growing Large	WGGA/WA/SWA	11.14	t
Inputs				
Petrol	Petrol combustion	SWA	6.10	L
Diesel	Diesel combustion	SWA	155.42	L
Electricity	Electricity, AU mix Vin Small	SWA	461.01	kWh
Irrigation (Small)	Water, groundwater, unspecified (other)	SWA/ABS	1.08	ML
	Water, surface water, river	SWA/ABS	2.12	ML
	Water, surface water, river (losses)	SWA/ABS	0.19	ML
	Electricity AU Mix Irrigation Small		200.9	kWh
Land Use	Occupation, arable lane, unspecified use	Definition	11,000	m2a
Urea	Urea modified	SWA	8.78	kg
Synthetic Nitrogen	Nitrogen Fertiliser, as N {RoW} | urea ammonium nitrate production | Alloc Def, U	SWA	13.37	kg N
Organic Nitrogen	Organic Nitrogen	SWA	9.73	kg N
PMS	Potassium Metabisulfite	Grower engagement	1.34	kg
Fertilizer Emissions	Fertilizer emissions small	NGA	0.093	kg N2O
Crop Residues	Crop Residues	NGA	0.013	t
Urea Hydrolysis	Urea Hydrolysis	SWA/NGA	8.78	kg Urea
Sprays	Pesticide	GrapeWeb (AgSmart Pty Ltd)	Modelled Appendix A	kg
Input transport	Transport, lorry 20-28t, fleet average/CH U AusSD/Link U	WGGA region weighted	48.92	tkm
Grape transport	Transport, articulated truck, >20t, customizable/AU U Grape Bin	WGGA region weighted	480.64	tkm

Land use was calculated based on the definition of a hectare. For medium and large sites, land use was increased by 10% to account for the area between blocks or vineyards.

Water use and irrigation splits were modelled for individual states and weighted based on findings through Australian Bureau of Statistics based on agricultural water use and irrigation water sources estimates by Australian Statistical Geography Standard (ASGS) for volume application to grapevines as well as irrigation providers who supply water throughout Australia and publish annual electricity use and delivery efficiency data (ABS 2022). See Table 10 for Australian breakdown for vineyard application.

Table 10: Agricultural water use, and irrigation water sources estimates by Australian Statistical Geography Standard (ABS 2022).

Water Source	Units	TAS	WA	SA	VIC	NSW
Volume water applied - Vineyards	**ML**	**2,194**	**17,736**	**221,246**	**125,430**	**141,722**
Irrigation Channels	ML	515	5,519	53,342	78,855	65,421
On-farm Dams	ML	720	2,630	3,923	2,834	6,980
Rivers	ML	816	652	62,276	23,625	44,369
Groundwater	ML	115	7,750	97,248	16,047	23,740
Recycled	ML	24	1,130	3,662	3,431	845
Towns/Mains	ML	5	54	794	593	347
Other	ML	0	1	1	44	21
Irrigation + Rivers	**ML**	**1,331**	**6,171**	**115,618**	**102,480**	**109,790**

4. Winery

4.1. Background

Grape intake begins in January and can go through until late April. Fermentation takes approximately two weeks from inoculation. After fermentation, the wines undergo stabilization, fining and filtration before aging in stainless steel tanks or barrels. The wine may remain in the winery anywhere from a few months, in the case of some white wines, to a number of years for premium red wines.

4.2. System Boundary

The system boundary for winemaking (Figure 10) includes all winemaking activities including crushing, fermentation, fining, stabilizing, filtering, aging, and packaging, as well as tank cleaning and wastewater treatment. The production of all inputs including electricity, fuel, winemaking additives and packaging material has been included, as well as their transport to the winery. The transport of grapes to the winery is included in the grape growing phase. Emissions from fermentation are not included in the scope of this study due to the short term nature of these emissions within the carbon cycle. This is further discussed in section 6.3 regarding biogenic carbon. Packaging has been discussed in Section 5.

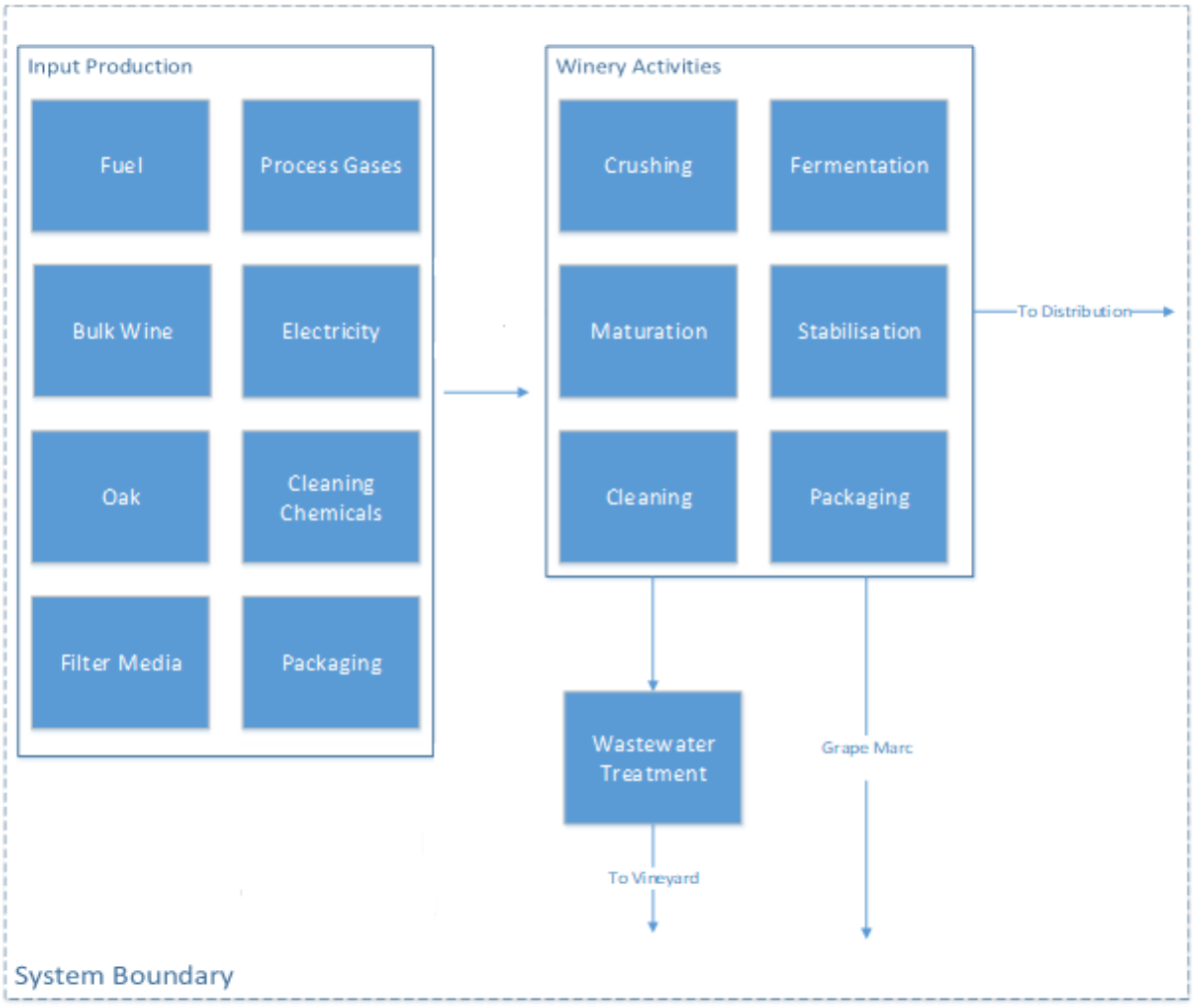


Figure 10: Winemaking system boundary

4.3 Size and state weighted winery production data

To define the weighting categories for wine production data, both by size and by state, the National Winegrape Grower Handbook (2013) from the Wine Grape Growers Association (see Appendix A), and recent crush and production figures as referenced through Wine Australia, and WGCSA were used. Extraction rates were applied respective of winery size (AWRI 2021) as per Table 11.. The state and sized based weighting categories which further defined allocation for electricity split on a national scale for winery sites are defined as per Table 12 below as well as the contribution of total wine production based on winery size:

Table 11: Estimated extraction rate for differing winery sizes (AWRI 2021).

Winery Size	Extraction Rate (L per tonne of grapes)
Small	600
Medium	650
Large	700

Table 12: State and size weighted winery contribution based on crush and estimated extraction rates (Wine Australia 2021, Winetitles 2021).

State	Winery Production Weighting		
	Small	Medium	Large
South Australia	43%	32%	55%
New South Wales	17%	23%	38%
Victoria	20%	24%	7%
Western Australia	15%	21%	0%
Tasmania	3%	0%	0%
Queensland	1%	0%	0%
Australian Capital Territory	0%	0%	0%
Contribution to total production (%)	**9%**	**17%**	**74%**

4.4.Modelling Methodology

The life cycle inventory was constructed using Simapro 9.4.0.1 software (Pré Consultants, 2022). Many of the input materials and processes were present in the AusLCI or Ecoinvent 3.8 databases and were used directly. These are noted in the LCI where used. Other processes required more detailed modelling or require some explanation and are described in the following sections.

4.4.1. Marc Disposal

Spent grape marc was treated as a waste product and transport was modelled from the winery using an estimate of product to an aggregation site or farm for further allocation hence the marc was considered to leave the production system. No emissions as a result of the breakdown of grape marc was attributed to the study.

4.5. Life Cycle Inventory

Primary data was taken from Sustainable Winegrowing Australia records for winery management. Data was collected for three years (from 2018/19 to 2020/21) and a median value was used from the aggregated data. The Winery production average was modelled based on contributions from small, medium and large winery data. The small, medium and large winery data inventories are as specified below in Table 13 to Table 15, respectively:

Table 13: Winemaking Data Sources for small producers

Basis	Unit Process	Databaseor Substance	Median (per kL)	Units
Wine	Winery Small	WGGA/WA/SWA	9%	% Weighted contribution
Wine	Winery Small	WGGA/WA/SWA	1	kL
Inputs				
Grape Growing Average (per kL)	Grape Growing Average	SWA	1.31	t
Water, Other	Water, river	SWA	2.62	kL
Land Use	Occupation, arable land, unspecified use	Definition	0	m^2a
Mains Water	Mains Water AU Mix Winemaking Small	SWA	0.66	kL
Electricity	Electricity AU Mix Wine Making Small	SWA	305.58	kWh
Purchased CO_2	Carbon dioxide liquid, at plant/RER U/AusSD U	SWA	10.05	kg
Oak	Oak	Winery models (existing)	4.29	p
Filter aids	Perlite, at mine/DE U/AusSD U	Winery models (existing)	33	kg
Refrigerants	Refrigerants	Winery models (existing)	21.7	kg
Cleaning Chemicals	Potassium hydroxide {GLO}| market for | APOS, U Citric acid {GLO}| market for | APOS, U	SWA	4.3	kg
Input Transport	Transport, lorry >28t, fleet average/CH U/AusSD/Link U	Google Maps (Estimate)	4,500	kgkm
Diesel (Stationary)	Diesel, combusted in industrial boiler/US	SWA	0.97	L
Petrol (Mobile)	Petrol Combustion	SWA	1.56	L
LPG (Stationary)	Liquefied petroleum gas, combusted in industrial boiler/US	SWA	7.89	L
Wastewater	Wastewater	SWA	3.58	kg

Table 14: Winemaking Data Sources for medium producers

Basis	Unit Process	Database or Substance	Median (per kL)	Units
Wine	Winery Medium	WGGA/WA/SWA	17%	% Weighted contribution
Wine	Winery Medium	WGGA/WA/SWA	1	kL
Inputs				
Grape Growing Average (per kL)	Grape Growing Average	SWA	1.31	t
Water, Other	Water, river	SWA	2.41	kL
Land Use	Occupation, arable land, unspecified use	Definition	0	m^2a
Mains Water	Mains Water AU Mix Winemaking Small	SWA	0.60	kL
Electricity	Electricity AU Mix Wine Making Small	SWA	228.72	kWh
Purchased CO_2	Carbon dioxide liquid, at plant/RER U/AusSD U	SWA	9.54	kg
Oak	Oak	Winery models (existing)	4.29	p
Filter aids	Perlite, at mine/DE U/AusSD U	Winery models (existing)	33	kg
Refrigerants	Refrigerants	Winery models (existing)	5.27	kg
Cleaning Chemicals	Potassium hydroxide {GLO}| market for | APOS, U Citric acid {GLO}| market for | APOS, U	SWA	4.3	kg
Input Transport	Transport, lorry >28t, fleet average/CH U/AusSD/Link U	Google Maps (Estimate)	4,500	kgkm
Diesel (Stationary)	Diesel, combusted in industrial boiler/US	SWA	0.53	L
Petrol (Mobile)	Petrol Combustion	SWA	0.13	L
LPG (Stationary)	Liquefied petroleum gas, combusted in industrial boiler/US	SWA	8.65	L
Wastewater	Wastewater	SWA	4.43	kg

Table 15: Winemaking Data Sources for large producers

Basis	Unit Process	Database or Substance	Median (per kL)	Units
Wine	Winery Large	WGGA/WA/SWA	74%	% Weighted contribution
Wine	Winery Large	WGGA/WA/SWA	1	kL
Inputs				
Grape Growing Average (per kL)	Grape Growing Average	SWA	1.31	t
Water, Other	Water, river	SWA	2.48	kL
Land Use	Occupation, arable land, unspecified use	Definition	0	m^2a
Mains Water	Mains Water AU Mix Winemaking Small	SWA	0.62	kL
Electricity	Electricity AU Mix Wine Making Small	SWA	149.47	kWh
Purchased CO_2	Carbon dioxide liquid, at plant/RER U/AusSD U	SWA	6.15	t
Oak	Oak	Winery models (existing)	4.29	p
Filter aids	Perlite, at mine/DE U/AusSD U	Winery models (existing)	33	kg
Refrigerants	Refrigerants	Winery models (existing)	0.23	kg
Cleaning Chemicals	Potassium hydroxide {GLO}| market for | APOS, U Citric acid {GLO}| market for | APOS, U	SWA	4.3	kg
Input Transport	Transport, lorry >28t, fleet average/CH U/AusSD/Link U	Google Maps (Estimate)	4,500	kgkm
Diesel (Stationary)	Diesel, combusted in industrial boiler/US	SWA	0.27	L
Petrol (Mobile)	Petrol Combustion	SWA	0.034	L
LPG (Stationary)	Liquefied petroleum gas, combusted in industrial boiler/US	SWA	1.71	L
Wastewater	Wastewater	SWA	3.42	kg

All input use and waste material generation data (Scope 1 and Scope 2) was taken from Sustainable Winegrowing Australia or existing case studies and reference models. Transport distances, including transport of fuel and other inputs for winemaking (Scope 3) were estimated based on average distance from capital city to regions based on state distribution of vineyards (Google Maps, 2022).

5. Packaging and Distribution

5.1. Background

Australian wines are sold both domestically and internationally to a number of different countries. Transport within Australia is generally conducted by road. International shipping generally occurs out of South Australia or Victoria. International shipping can occur pre- or post-packaging. If wine is internationally shipped pre-package, regarded as in bulk, packaging occurs in the destination market.

Australian wines packaged and sold in the domestic market are primarily packaged in two formats: glass bottle with a 750ml volume or cask/Bag-in-Box/soft-pack format (ABS 2014). There exist a host of alternative packaging formats within each of these formats with an ever-expanding introduction of new formats and technologies (i.e. canned wine, r-PET packaging etc.), however these packaging types at present do not possess a significant market share compared to glass or cask products by volume.

5.2. System Boundary

The system boundary for distribution is shown below (Figure 11). The system boundary for distribution includes transport to the retailer but does not include consumer transport to purchase the product.

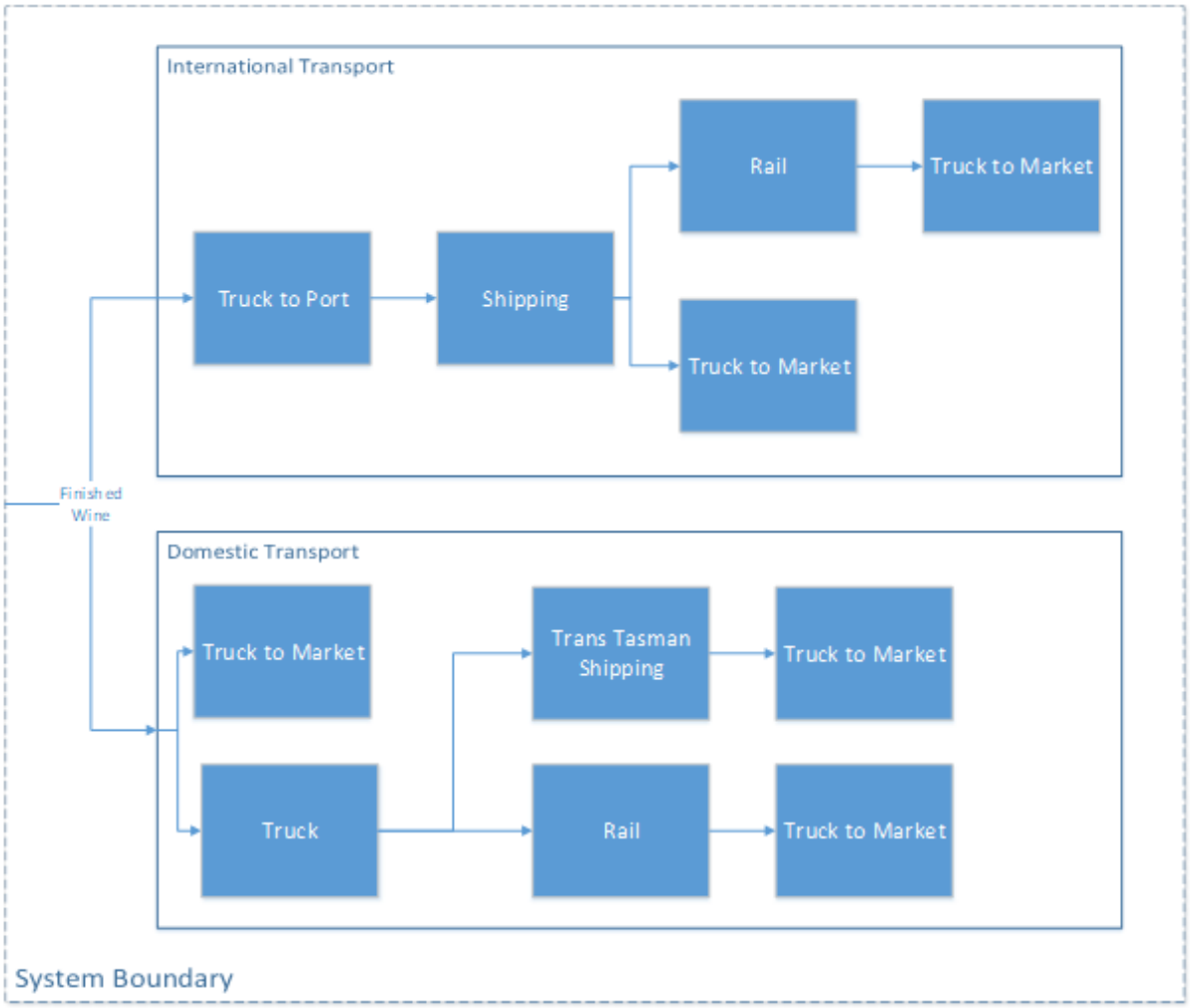


Figure 11: Distribution System Boundary

5.3. Modelling Methodology

5.3.1 Packaging

Based on data from Australian Bureau of Statistics (2014) and 2020 – 2021 Australian Wine: Production, Sales and Inventory reports, the breakdown of packaging format in Australia was estimated to be 68% as packed in glass bottle (nominal volume 750ml) and 32% in cask or BiB format (nominal volume 2L). Domestic sales of wine packaged in Australia was extracted from the 2020 – 2021 Australian Wine: Production, Sales and Inventory reports. In 2020-2021, domestic sales of Australian wine were 393 million litres of still wine.

Of the wine packaged in glass bottle within the Australian market for domestic distribution, screw cap closures were modelled as the primary packaging selection, with cork modelled based on a small contribution of Australian wines under this format. Data as captured from the AWRI Vineyard and Winery Practices Survey (AWRI 2019) for closure use in Australian wine is as shown in Table 16 showing the dominance of the screw cap format in the Australian market. No reliable models or published data exists for screwcap production. AWRI performed a brief study for a screwcap manufacturer in 2010. The study is not provided for publication

Table 16: Closure use for still wine packaging in Australia (AWRI 2016)

Closure	Red still wine	White still wine
Screw Cap	81%	95%
Cork	13%	1%
Synthetic	6%	3%

Data presented in Table 16 is only for wine bottled in Australia, not wine exported in bulk and bottled overseas. A significant proportion of the product packaged under cork was regarded as for export due to certain export markets preference to wine packaged under this format.

Glass bottle emissions were modelled based on a standard punted claret bottle with bottle mass of 500g. The model used for glass was modified to incorporate LCA data from O-I (2010), who are one of the major glass suppliers for wine packaging globally. Published data for an NSW glass plant (using Asia Pacific average electricity) gave greenhouse gas emissions of 0.153 kg CO_2e per average 355ml beer bottle (194g from USA). This equated to approximately 0.79 kg CO_2e/kg glass and was modified to reflect current electricity country mix contributions and the bottle mass considerations as reflected for wine bottles.

The recycling rate of glass was a further modification applied to the glass bottle emissions model, with recycling rates being a key shift in the packaging process since the 2016 model was undertaken Considering both domestic and export markets for glass production (primary export markets being Europe and US), recycling rates within each market are as defined in Table 17. Export volumes (section 5.3.2) were weighted with respect to market with the applied glass recycling rate then applied to that market (i.e. European glass recycling rates were applied to export volumes delivered in bulk to all European markets, including the United Kingdom).

Table 17: Global recycling rate changes for glass bottles. 2016 vs. 2022.

Market	2016	2022	Data Source
Europe	47%	52%	FEVE (The European Container Glass Federation) – (2022)
Asia Pacific	25%	40%	Department of the Environment and Energy (2019)
America	25%	33%	Various Sources (2018 – 2022)

Primary packaging data was modelled as per the inventory per bottle in Table 18:

Table 18: Primary packaging inventory for glass bottle packaging in Australia

Basis			Value (L)	Units
Bottle Packaging AU			0.75	L
Inputs	Data Source	Database or Substance	Contribution	Units
Glass	Packaging glass, green, at plant/RER U/AusSD U - modified	AUSLCI	0.5	kg
Screw Cap	Screw Cap (3105) Box, Packaged at gate	AWRI Internal	0.00027	p
Label	Kraft paper, bleached, at plant/RER U/AusSD U	AUSLCI	0.5	g
Cardboard	Corrugated board, recycling fibre, double wall, at plant/CH U/AusSD S	AUSLCI	0.044	kg
Transport	Transport, lorry >28t, fleet average/CH U/AusSD/Link U	AUSLCI	43	kgkm

No reliable models or published data exists for cask production. AWRI performed a brief study for a cask manufacturer in 2010. The study is not provided for publication. Transport for production inputs was modelled based on AUSLCI process Transport, lorry >28t, fleet average/CH U/AusSD/Link U.

5.3.2 Distribution

The split of Australian export market figures versus domestic figures was extracted from the 2020 – 2021 Australian Wine: Production, Sales and Inventory reported as released by Wine Australia specifying domestic sales in 2021, and the Australian Wine Export Summary specifying export markets, including volume and packaging type.

Domestic sales of Australian still wine packaged in Australia equated to 393 million litres in 2020-2021. The current state of Australian wine exports shows a recent downturn relative to previous years with significant volume reductions attributed to increased tariffs upon exporting to mainland China. Export figures up to June 2022 for Australian wine were at 625 million litres. Of the wine exported, 384 million litres was exported in bulk, while 233 million litres was packaged domestically and exported in bottle. Approximately 1% of Australian wine exported was delivered in an alternative packaging

format (not glass bottle), however as this contribution in the current market is negligible this was not modelled.

Of the proportion of Australian wine exported in bulk, the use of flexitanks is the preferred mechanism comparative to ISO tanks (AWRI 2019). Based on the AWRI Vineyard and Winery Practices Survey, 90% of bulk export containers from Australia use flexitank. No reliable models or published data exists for flexitank production and packaging. AWRI performed a brief study for bulk wine transfer and flexitank manufacturer in 2010. The inventory is not provided for publication.

The contribution of Australian wine produced and sold domestically versus internationally was modelled as per Table 19:

Table 19: Sales formats for Australian wine

Domestic Sales	**39%**	**Export Sales**	**61%**
Cask or Bag-in-Box	32%	Bulk	62%
Bottle	68%	Bottle	38%

The ten primary export markets for Australian still wine delivered in bulk wine as per the Wine Australia export dashboard (Wine Australia 2022) are shown in Table 20:

The ten primary export markets for Australian still wine delivered in bottle as per the Wine Australia export dashboard (Wine Australia 2022) are shown in Table 21:

The market destinations were used to develop transport pathways for all the wine produced in Australia. Assumptions were made about the most likely ports for each country and then the transport pathway within that country that would represent an average scenario. Shipping routes were calculated from SeaRates (2022).

Table 20: Distribution Distances (km) of Australian top ten bulk wine export markets

Export Market (exported in Bulk)					
Country	Destination Port	Export Volume (million L)	Shipping Leg (km)	Rail Leg (km)	International Road Leg (km)
United Kingdom	Tilbury	192,165,005	15,616	500	100
United States of America	New York	58,863,138	19,168		200
Germany	Hamburg	30,727,204	20,466	471	50
Canada	Halifax/Vancouver	29,927686	18,422	100	50
Denmark	Hamburg	17,130,998	20,466	471	50
New Zealand	Auckland	13,011,950	3,821		50
France	Hamburg	9,289,877.8	20,466	471	50
Belgium	Hamburg	7,809,242	20,466	471	50
China mainland	Hong Kong	4,820,575	8,825		50
Japan	Tokyo	4,757,740	11,882	200	50

Table 21: Distribution Distances (km) of Australian top ten bottled wine export markets

Export Market (exported in glass bottle)					
Country	Destination Port	Export Volume (million L)	Shipping Leg (km)	Rail Leg (km)	International Road Leg (km)
United States of America	New York	79,729,592	19,168		200
United Kingdom	Tilbury	35,259,369	15,616	500	100
Canada	Halifax/Vancouver	23,267,603	20,466	471	50
New Zealand	Auckalnd	18,176,087	3,821		50
Singapore	Singapore	8,002,288	20,466	471	50
Hong Kong	Hong Kong	6,929,540	8,825		50
Japan	Tokyo	6,739,746	11,882	200	50
Netherlands	Hamburg	6,003,114	20,466	471	50
India	Cochin	4,233,548	10,439	1,341	100
South Korea	Seoul	3,946,860	10,403		50

Transport weights were determined by the product category sent, based on bottle mass and Flexitank mass as fully loaded, with estimates of secondary packaging.

6. Results

The impacts of Australian wine production were analysed in the life cycle impact assessment (LCIA) phase according to the methods outlined in Section 2.2. The breakdown within the five main impact categories are presented in the figures and tables below, with the other inventory categories presented throughout the report.

The LCIA results are relative expressions and do not predict the impacts on category endpoints, the exceeding of environmental thresholds, safety margins or risks.

The analysis has been split into five primary categories:

1. Grape growing
2. Winemaking
3. Transport
4. Destination Bottling
5. Packaging

The indicative cradle-to-grave carbon footprint of Australian wine was calculated to be 1.05 kg CO_2e per L. Comparative to the 2016 study (1.16 kg CO_2e per L) a 10% reduction per L of Australian wine produced was recognised. Table 22 provides a breakdown of the contributing factors that make up the industries emission profile based on a percentage of influence.

Table 22: Life cycle impacts per L of Australian Wine

	Greenhouse Gas Emissions (kg CO_2e per L)	Greenhouse Gas Emissions (kg CO_2e per L)
Year	**2016**	**Current**
Grape Growing	15%	13%
Wine Making	17%	13%
Packaging	28%	27%
Transport	24%	26%
Destination Bottling	17%	20%
Total kg CO_2e per L	**1.16**	**1.05**
Share of Life Cycle	**100%**	**100%**

6.1 Grape Growing

The Grape growing module impacts are detailed according to Table 23 below. The analysis showed that for an average L of Australian wine produced, grape growing contributes a greenhouse gas emission footprint of 0.137 kg CO_2e. This module is further broken down in Figure 12 demonstrating a Sankey Diagram (a visualization of the flow of emissions from one input category to another) showing a weighted average input for the Australian grape growing average model.

Table 23: Grape Growing Impacts per L wine.

	Greenhouse Gas Emissions (kg CO_2e per L)	Greenhouse Gas Emissions (kg CO_2e per L)
Year	2016	Current
Electricity	27%	26%
Diesel	40%	44%
Irrigation	19%	15%
Fertilizer	5%	3%
Grape Transport	4%	5%
Agrochemicals	3%	3%
N2O emissions	2%	4%
Total	0.171	0.137

Comparing grape growing data to the 2016 model, we see a contribution decrease of greenhouse gas emissions (kg CO_2e) by 0.034kg CO_2e per L. The decrease based on the modelling is primarily driven by the decrease in emissions attributed to electricity for onsite use and as used by irrigation providers, given the increasing penetration to renewables for each of the states with higher growing zones.

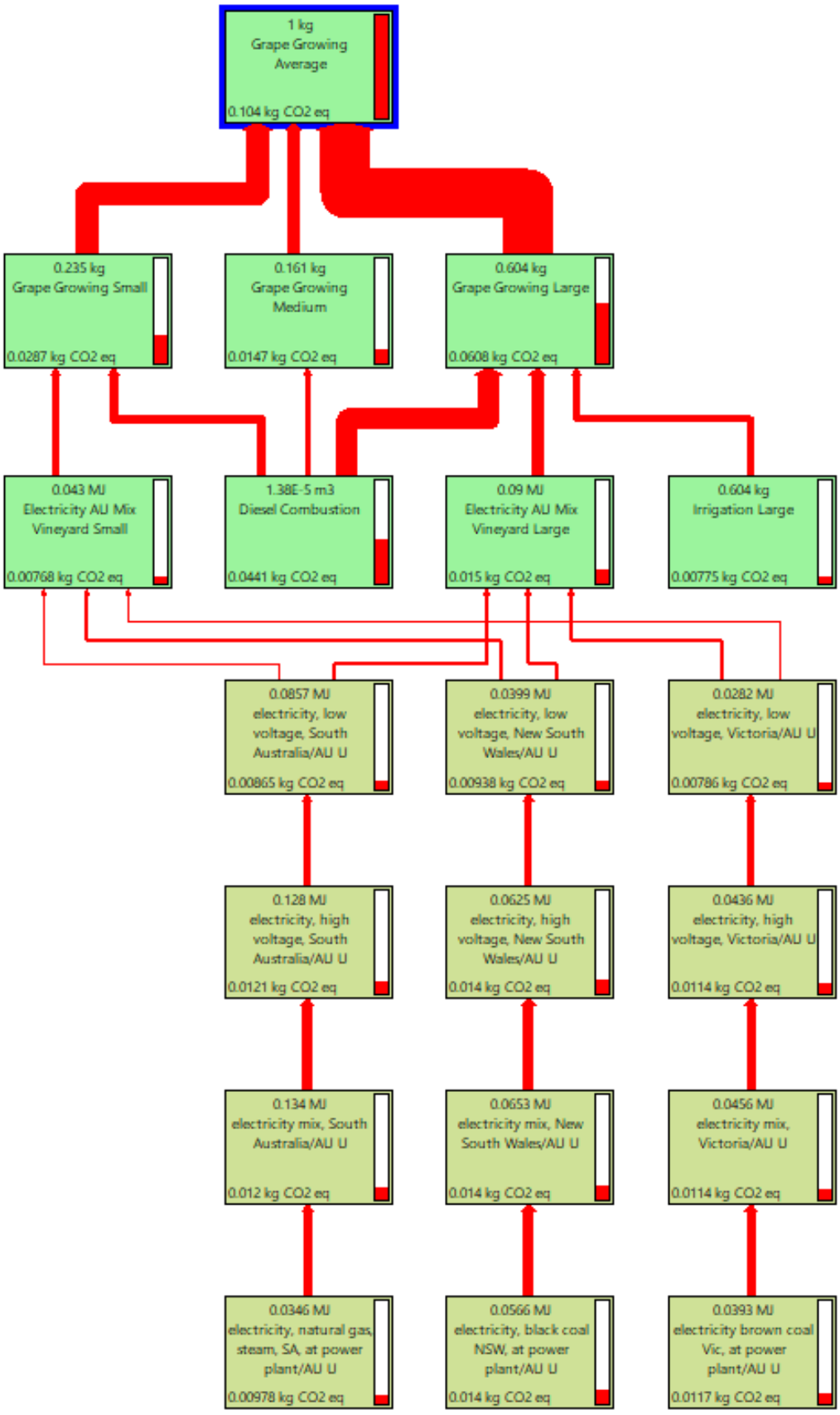


Figure 12: Sankey Diagram representing LCIA for Green House Gas emissions of Australian Sector grapegrowing.

6.2 Winemaking

The winemaking module impacts are detailed according to Table 24 below. The winemaking module includes onsite winery operations: the combustion of fuels, release of process gases, use of electricity, use of water (though excluding delivery of water), release of refrigerants, transport of inputs to the site and grape marc from the site, and treatment of wastewater. The analysis showed that for an average litre of Australian wine produced, winemaking contributes a greenhouse gas emission footprint of 0.139 kg CO_2e per litre. This module is further broken down in Figure 13 demonstrating a Sankey Diagram showing a weighted average input for the Australian winemaking average model.

Table 24: Winemaking Impacts per L wine.

	Greenhouse Gas Emissions (kg CO_2e per L)	Greenhouse Gas Emissions (kg CO_2e per L)
Year	2016	Current
Electricity	80%	72%
LPG	4%	6%
Citric acid	5%	7%
Caustic	3%	4%
Refrigerants	3%	4%
Purchased CO_2 / Dry Ice	3%	4%
Wastewater	2%	3%
Total	**0.193**	**0.139**

Comparing winemaking data to the 2016 model, we observe a contribution decrease of greenhouse gas emissions (kg CO_2e) by 0.054kg CO_2e per L wine. The decrease based on the modelling is primarily driven by the decrease in emissions attributed to electricity for onsite use given the increasing penetration to renewables for each of the states with higher producing regions. Based on previous winery energy audits undertaken at the AWRI, the greatest proportion of on-site electricity is for use in refrigeration, however, includes contributions from other elements including boilers, winery equipment, pumping, lighting and compressed air (Figure 14).

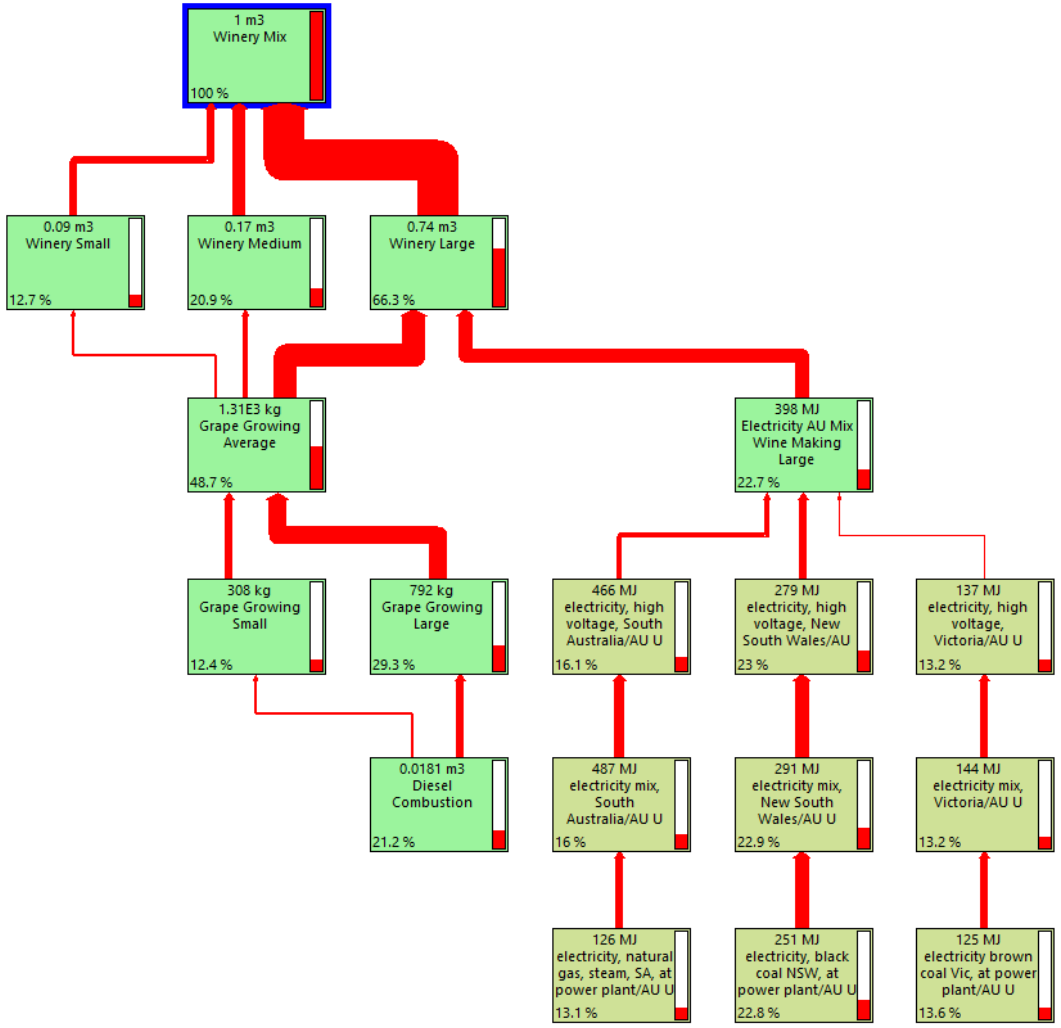


Figure 13: Sankey Diagram representing LCIA for Green House Gas emissions of Australian Sector winemaking.

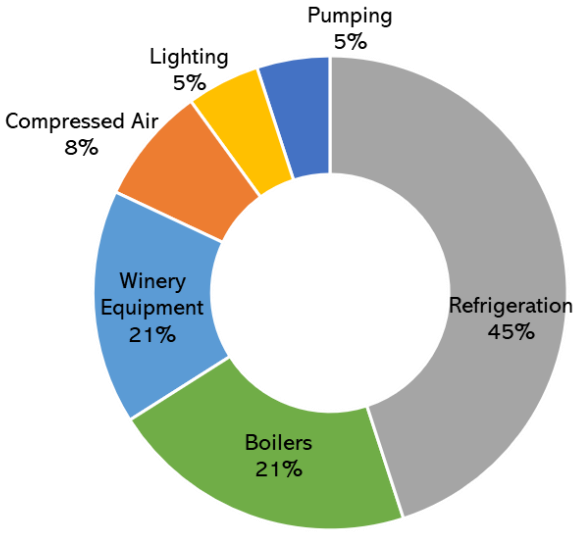


Figure 14: Winery energy audit outcomes (AWRI 2016)

In summary, a detailed breakdown of the input contributions from vineyard and winery practices is detailed in Figure 15.

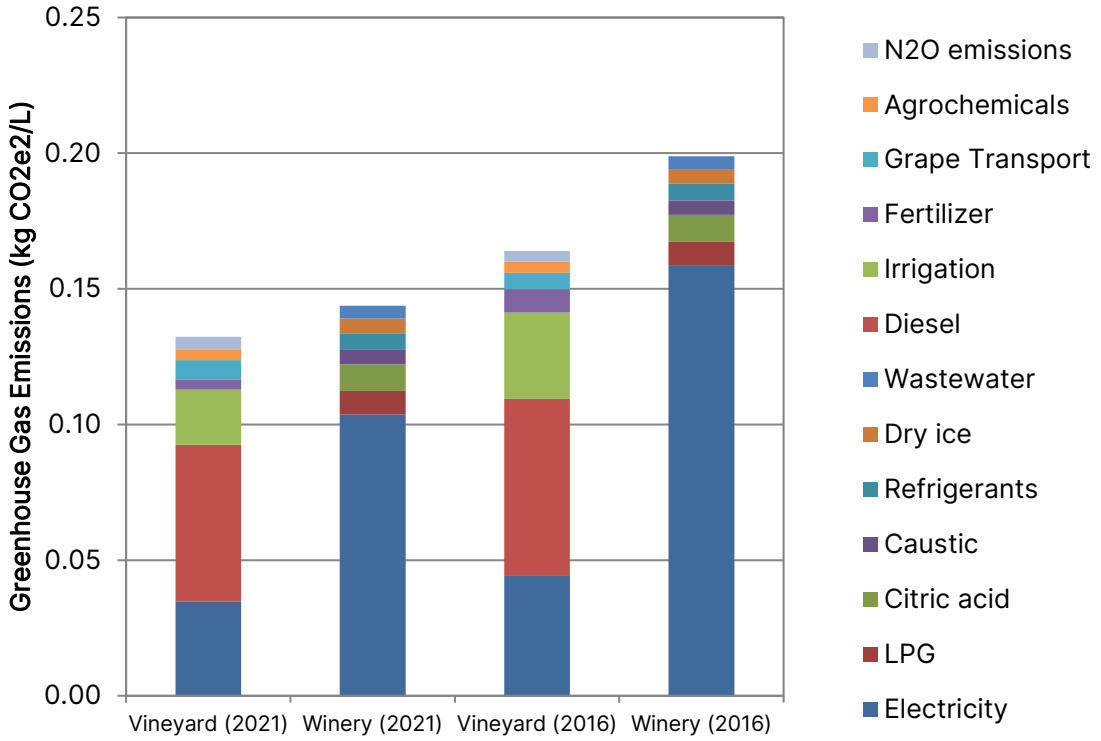


Figure 15: Australian vineyard and winery emission sources

6.3 Packaging, transportation and destination bottling

At the end of the winemaking process, wine has many alternative pathways in which it could be delivered to the final consumer. The LCIA identifies four potential scenarios with which a wine could be transported and packaged. These include:

1. Packaged into cask and transported in the domestic market.
2. Packaged into glass bottle and transported in the domestic market.
3. Exported in bulk and packaged in the destination market prior to distribution within that market.
4. Exported in bottle and distributed within that market.

6.3.1 Domestic market, cask packaging

The module defined below assesses the impacts of a cask wine packaged in the domestic market (cradle to gate) and transported for distribution within the same market (cradle to grave). The domestic market, cask packaging module impacts are detailed according to Table 25 below This module is further broken down in Figure 16.

Table 25: Emission impacts of a cask wine packaged in the domestic market (cradle to gate) and transported for distribution within the same market (cradle to grave).

	Greenhouse Gas Emissions (kg CO_2e per L)	Greenhouse Gas Emissions (kg CO_2e per L)
Year	**2016**	**Current**
Grape Growing	0.171	0.137
Winemaking	0.193	0.139
Packaging	0.107	0.056
Transport	0.143	0.145
Total (Cradle to gate)	**0.471**	**0.332**
Total (Cradle to grave)	**0.614**	**0.477**

The production of primary packaging, i.e. cask, was the major impact driving change between the previous study and the current study due to reliance upon electricity as modelled within the cask production. Based on a cradle-to-grave assessment, a reduction of 0.137kg CO_2e per L of wine was observed.

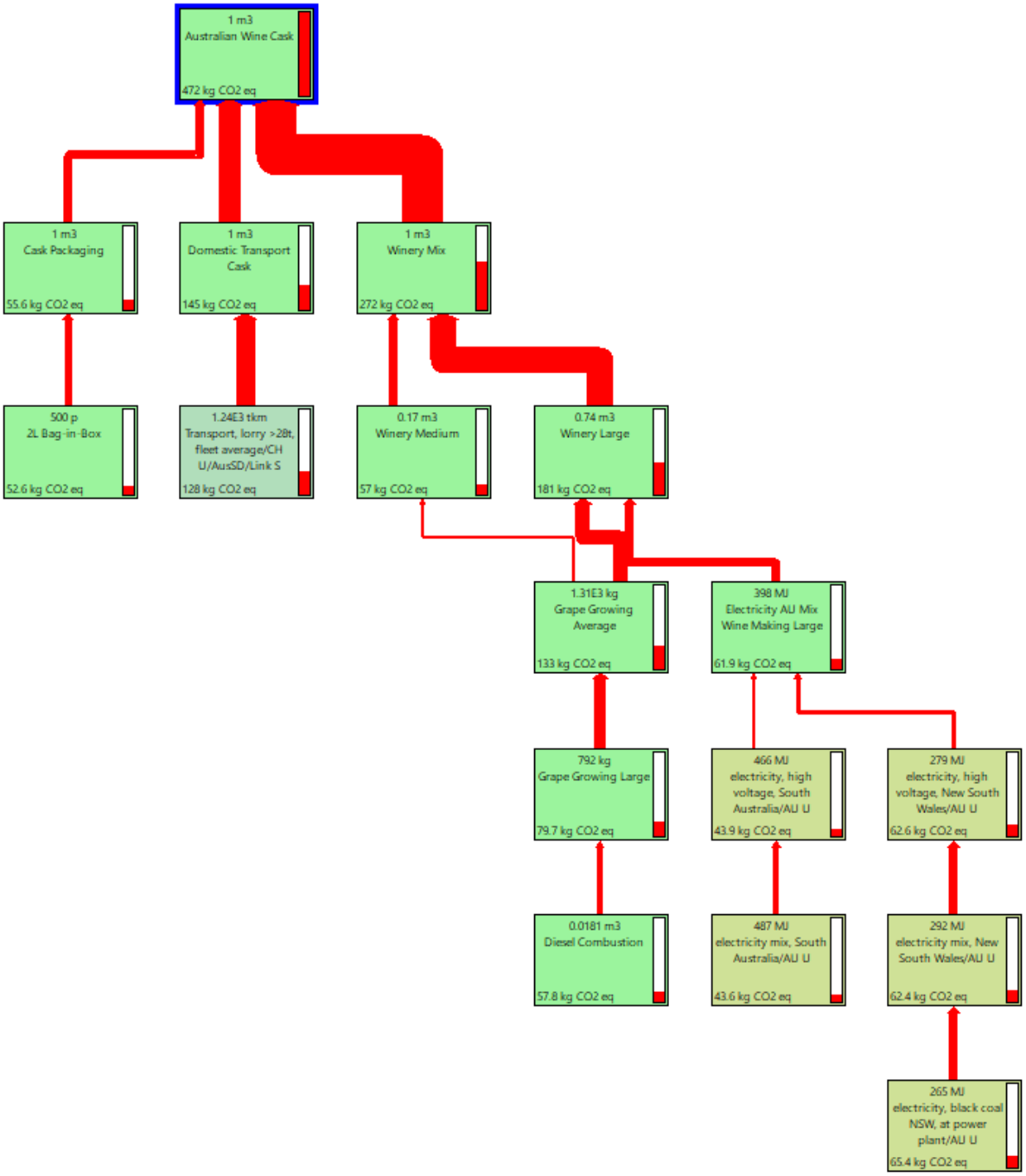


Figure 16: Sankey Diagram representing LCIA for Green House Gas emissions of domestic cask packaging and distribution.

6.3.2 Domestic market, bottle packaging

The module defined below assesses the impacts of a glass bottle of wine packaged in the domestic market (cradle to gate) and transported for distribution within the same market (cradle to grave). The domestic market, bottle packaging module impacts are detailed according to Table 26 below This module is further broken down in Figure 17.

Table 26: Emission impacts of a bottled wine packaged in the domestic market (cradle to gate) and transported for distribution within the same market (cradle to grave).

	Greenhouse Gas Emissions (kg CO_2e per L)	Greenhouse Gas Emissions (kg CO_2e per L)
Year	**2016**	**Current**
Grape Growing	0.171	0.137
Winemaking	0.193	0.139
Packaging	0.587	0.578
Transport	0.225	0.226
Total (Cradle to gate)	**0.951**	**0.854**
Total (Cradle to grave)	**1.176**	**1.080**

The production of primary packaging, i.e. glass bottle, was the major impact in the total greenhouse gas emissions of a domestic market packaged product. The increased glass recycling rate (i.e. proportion of cullet in a standard bottle) has positively impacted the packaging emissions for this format and with increased capacity in this area, will continue to provide emissions reductions. Based on a cradle-to-grave assessment, a reduction of 0.096kg CO_2e per L of wine was observed.

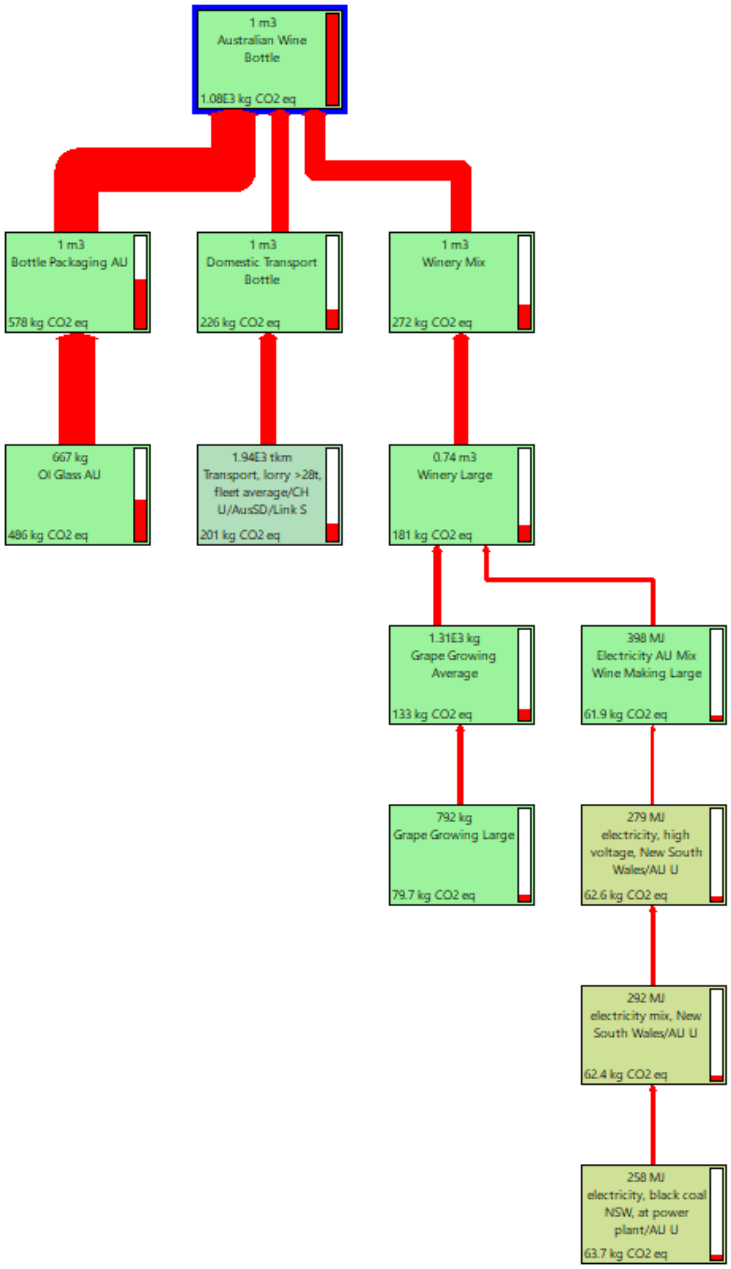


Figure 17: Sankey Diagram representing LCIA for Green House Gas emissions of domestic bottled wine packaging and distribution.

6.3.3 Export market, exported in bulk

The module defined below assesses the impacts of wine exported to global markets in bulk (i.e. flexitanks) and packaged in the destination market, with subsequent distribution in the intended market. A cradle-to-gate assessment here is defined at the point of finished wine production once wine leaves the winery gate, while a cradle-to-grave assessment identifies the freight to and within the export market, and subsequent packaging in the destination market. The export market, bulk wine module impacts are detailed according to Table 27 below. This module is further broken down in Figure 18.

Table 27: Emission impacts of a bulk wine exported and packaged in bottle in an export market.

	Greenhouse Gas Emissions (kg CO_2e per L)	Greenhouse Gas Emissions (kg CO_2e per L)
Year	**2016**	**Current**
Grape Growing	0.171	0.137
Winemaking	0.193	0.139
Packaging		
Transport	0.273	0.274
Destination Bottling	0.533	0.539
Total (Cradle to gate)	**0.364**	**0.276**
Total (Cradle to grave)	**1.170**	**1.089**

The 2021/2022 export markets for Australian Wine have observed a marginal, but noticeable, shift towards European markets since 2016, with areas of Asia-Pacific limiting their imports of Australian wine. Since 2016, the recycling rates of glass produced in European destinations has improved (47% to 52%) hence observing a decrease in emissions overall. Based on a cradle-to-grave assessment, a reduction of 0.081kg CO_2e per L of wine was observed. The results show there exists a comparative footprint in exporting wine in bulk and packaging in international markets compared to Australian glass bottle packaging and distribution in the domestic market. The combined effects of the improved recycling rates in the primary export markets and the higher renewable energy contribution within these markets plays a key role in this observed effect. This outcome displays improvement opportunities for the Australian market in these areas to align with global leaders.

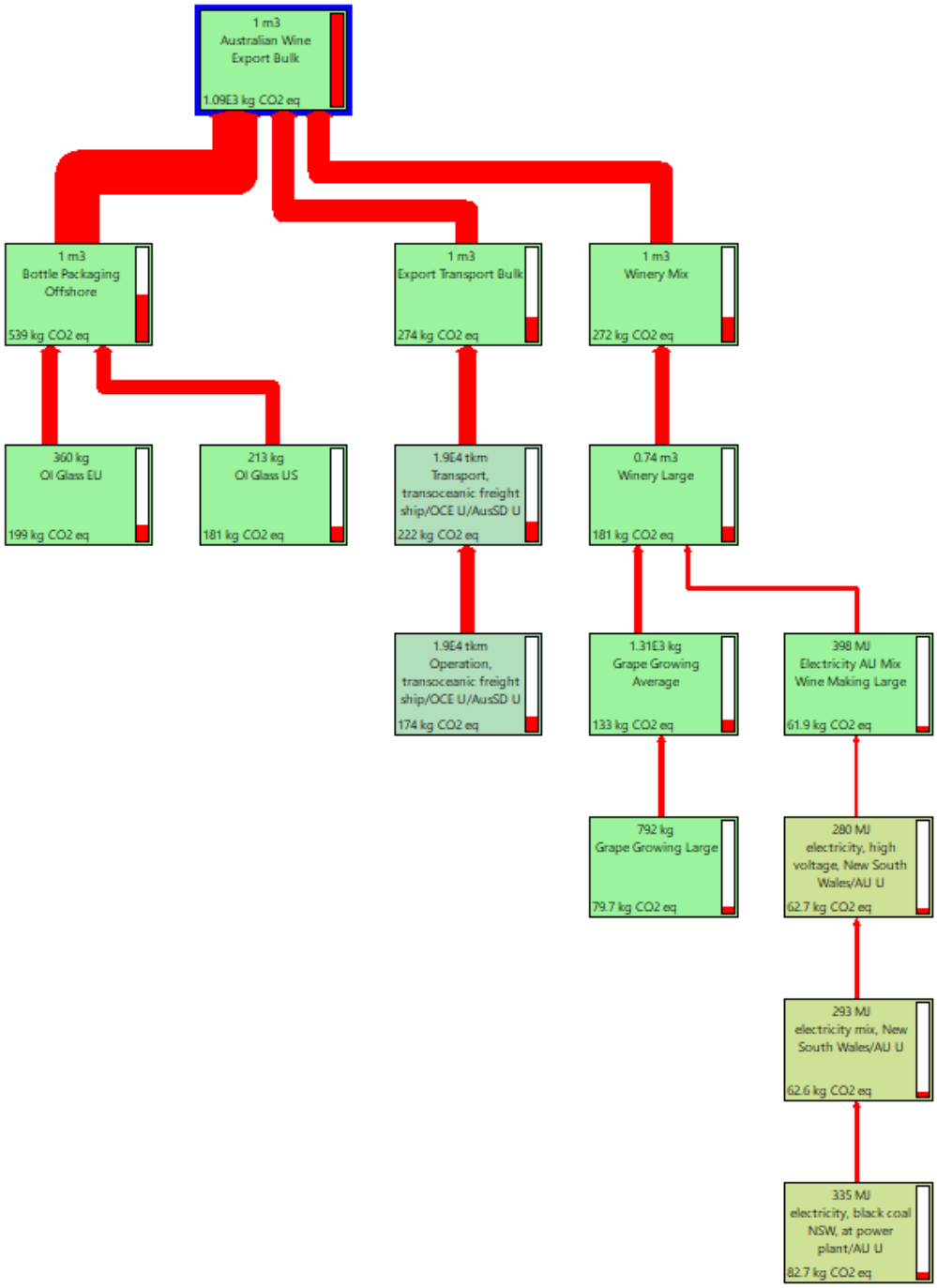


Figure 18: Sankey Diagram representing LCIA for Green House Gas emissions of bulk wine exported and packaged in the destination market.

6.3.4 Export market, exported in bottle

The module defined below assesses the impacts of wine exported to global markets in bottle (i.e. glass bottles), packaged in Australia, with distribution and transport in the export market. A cradle-to-gate assessment here is defined at the point of finished wine production and packed leaving the winery gate, while a cradle-to-grave assessment identifies the freight to and within the export market. The export market bottled wine module impacts are detailed according to Table 28 below. This module is further broken down in Figure 19.

Table 28: Emission impacts of a bulk wine exported in bottle and distributed in the export market.

	Greenhouse Gas Emissions (kg CO_2e per L)	Greenhouse Gas Emissions (kg CO_2e per L)
Year	**2016**	**Current**
Grape Growing	0.171	0.137
Winemaking	0.193	0.139
Packaging	0.587	0.578
Transport	0.394	0.395
Total (Cradle to gate)	**0.951**	**0.854**
Total (Cradle to grave)	**1.345**	**1.249**

As per packaging of glass bottles in the domestic market, the production of primary packaging was the major impact in the total greenhouse gas emissions of glass bottles exported globally. The increased glass recycling rate (i.e. proportion of cullet in a standard bottle) has positively impacted the emissions for this packaging format and with increased capacity in this area, will continue to provide emissions reductions. Based on a cradle-to-grave assessment, a reduction of 0.096kg CO_2e per L of wine was observed.

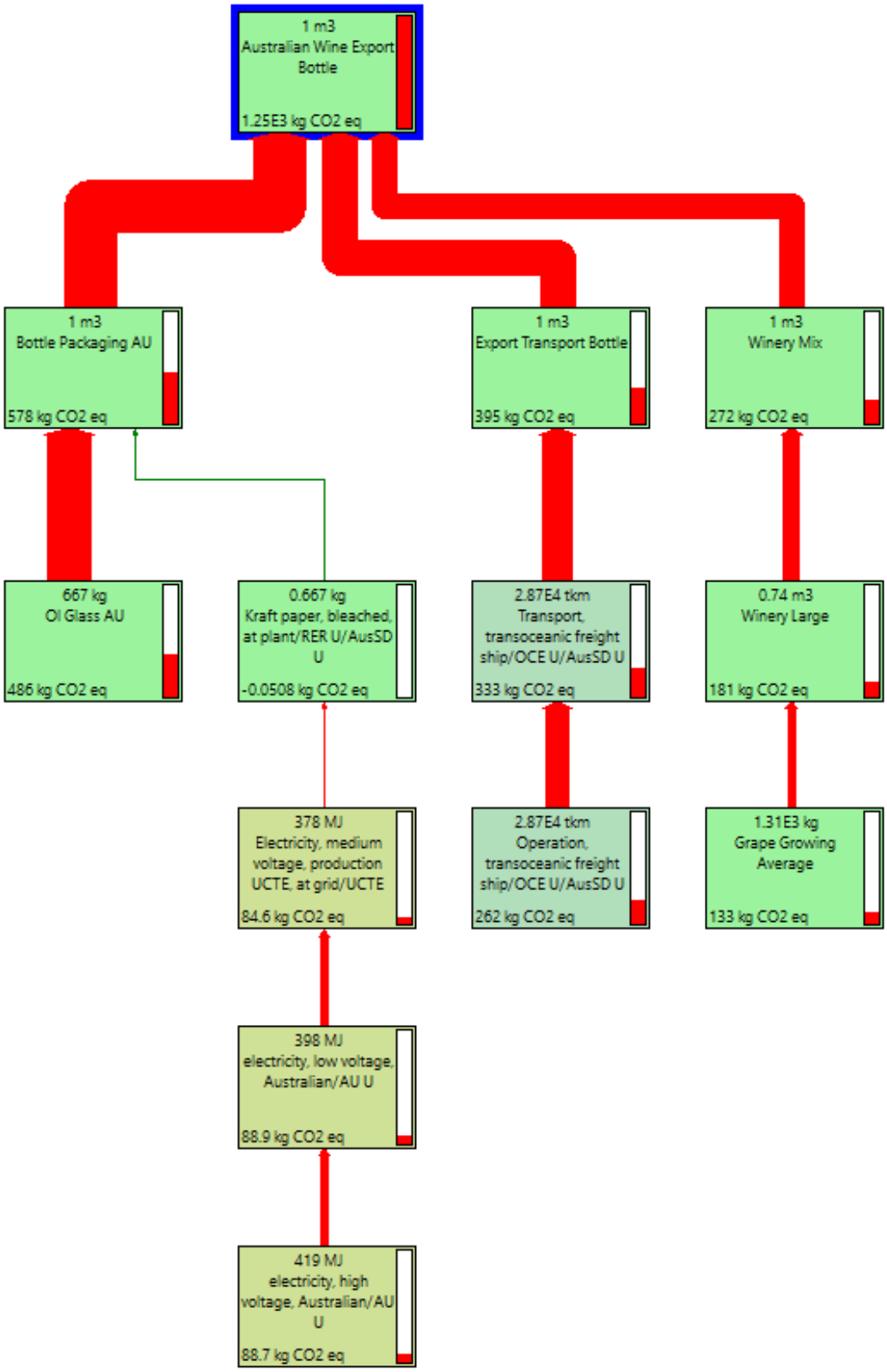


Figure 19: Sankey Diagram representing LCIA for Green House Gas emissions of bottled wine exported and distributed in the destination market.

6.3.5 Australian Wine Greenhouse Gas Emissions (kg CO_2e) based on distribution

The previous sub sections have aimed to factor in all the viticultural and winemaking practices, as well as the primary packaging and distribution requirements that best highlight the production and final destination of Australian wine. To summarise the story with respect to impact category underpinning the assessment, Greenhouse Gas Emissions (kg CO_2e), we observe that carbon footprint of Australian Wine, assessed through a cradle to grave LCA approach ranges between 0.48 – 1.25 kg CO_2e per L (Figure 20).

Comparing against the model developed for Australian wine in 2016, we see there is reduction in the average carbon footprint across all scenarios and distribution pathways. The reduction in most instances is in the order of 0.1 kg CO_2e, or approximately 5 – 10%. The electricity mix of Australian states and territories is the primary driver for this reduction as attributed to the penetration to renewable energy sources.

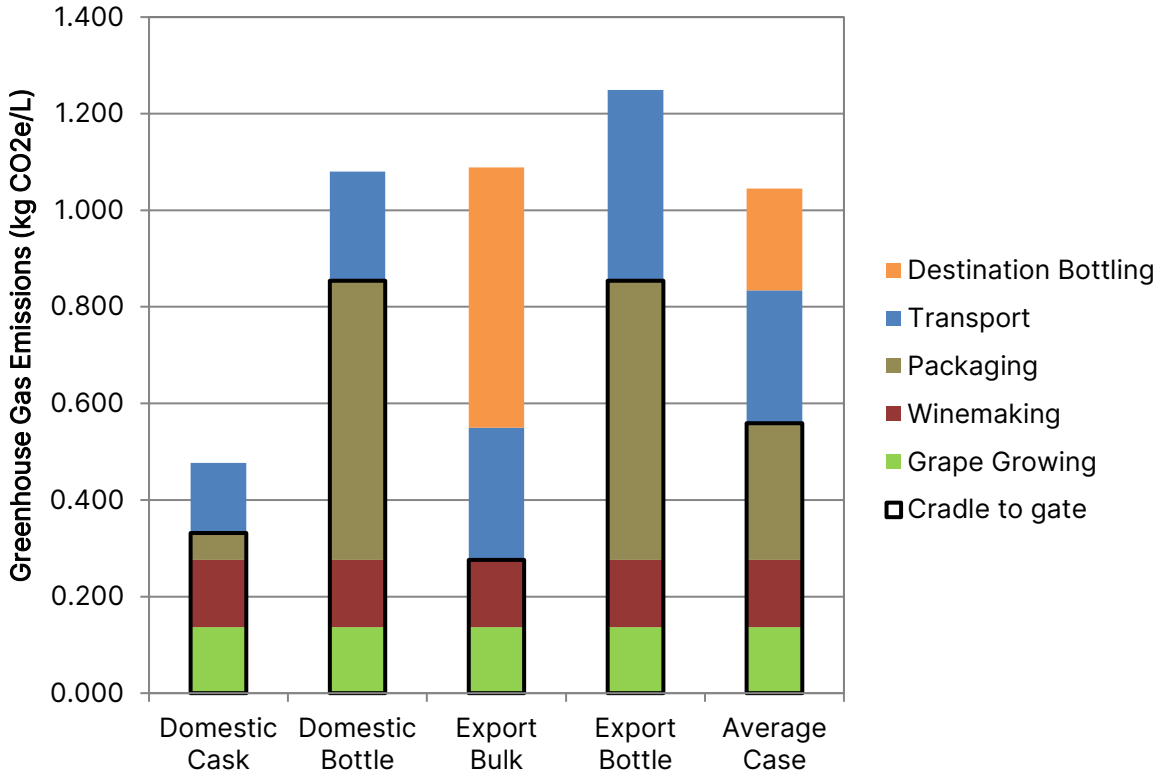


Figure 20: Greenhouse gas emissions of Australian wine delivered to domestic and export markets in different formats, showing both cradle to grave and cradle to gate emissions.

6.4 Packaging based sensitivity analysis

A number of opportunities and/or scenarios were additionally modelled to better understand the impact category differences between different packaging formats. These scenarios were modelled based on the 2016 models, with updated databases and conditions applied.

6.4.1 Cask size versus bottle weight

Packaging variations exist for wine in both the domestic and export markets. An ever-increasing number of new packaging formats are finding their way into the supply chain, with suppliers focusing on the trends observed throughout industry and highlighted here, which show that package type and transport of such package type can have a considerable impact on the greenhouse gas emissions of a product.

In Australia, cask (or Bag-in-Box) and glass bottles are the two primary packaging formats. However, within these formats there exists numerous options, sizes, suppliers, manufacturers and distributors. For bag-in-box wine, there has been a recent push towards smaller format products, with a noticeable market shift from 4L to 2L products. For glass bottles, a number of producers nationwide have made a significant commitment to light weight glass through their high-volume product ranges with bottles from O-I and Visy supporting this transition. The common light weight bottles range between 330g (minimum) to 400g for a 750mL volume, while the standard bottle weight continues to be around the 500g weight as modelled within the current LCA.

The modelling was performed to analyze the effect of reducing the weight of a bottle or reducing the volume of a cask to determine the overall impact on the cradle to grave LCA of Australian wine distributed in the domestic market. A premium grade bottle, with weight identified at 750g has additionally been factored into the analysis to show how this might impact on overall outcomes.

Table 29 identifies the contribution of each of the primary categories to the LCIA of greenhouse gas emissions for a L of Australian wine. Figure 21 further breaks this representation down visually. The Greenhouse Gas Emissions (kg CO_2e) for a L of wine packaged in a cask range in the extent of 45% less than that of a standard glass bottle (500g). Light weight bottles (330g) reduce the Greenhouse Gas Emissions (kg CO_2e) of a L of wine by 14% compared to a standard bottle, while increasing the weight of a bottle to premium category (750g) can increase the Greenhouse Gas Emissions (kg CO_2e) of a L of wine by 21% compared to a standard bottle. Cask size showed to have limited effect on the cradle to grave Greenhouse Gas Emissions (kg CO_2e) of cask wine.

Table 29: Contribution of GHG emissions of primary categories as influenced by packaging type.

Primary Production Category	Packaging Alternatives				
	2L Cask	4L Cask	330g Glass	500g Glass	750g Glass
Grape Growing	0.137	0.137	0.137	0.137	0.137
Winemaking	0.139	0.139	0.139	0.139	0.139
Packaging	0.056	0.044	0.413	0.578	0.822
Transport	0.145	0.145	0.196	0.226	0.271
Greenhouse Gas Emissions (kg CO_2e)	**0.477**	**0.465**	**0.885**	**1.080**	**1.369**
Percentage reduction (kg CO_2e)	**35%**	**34%**	**65%**	**79%**	**100%**

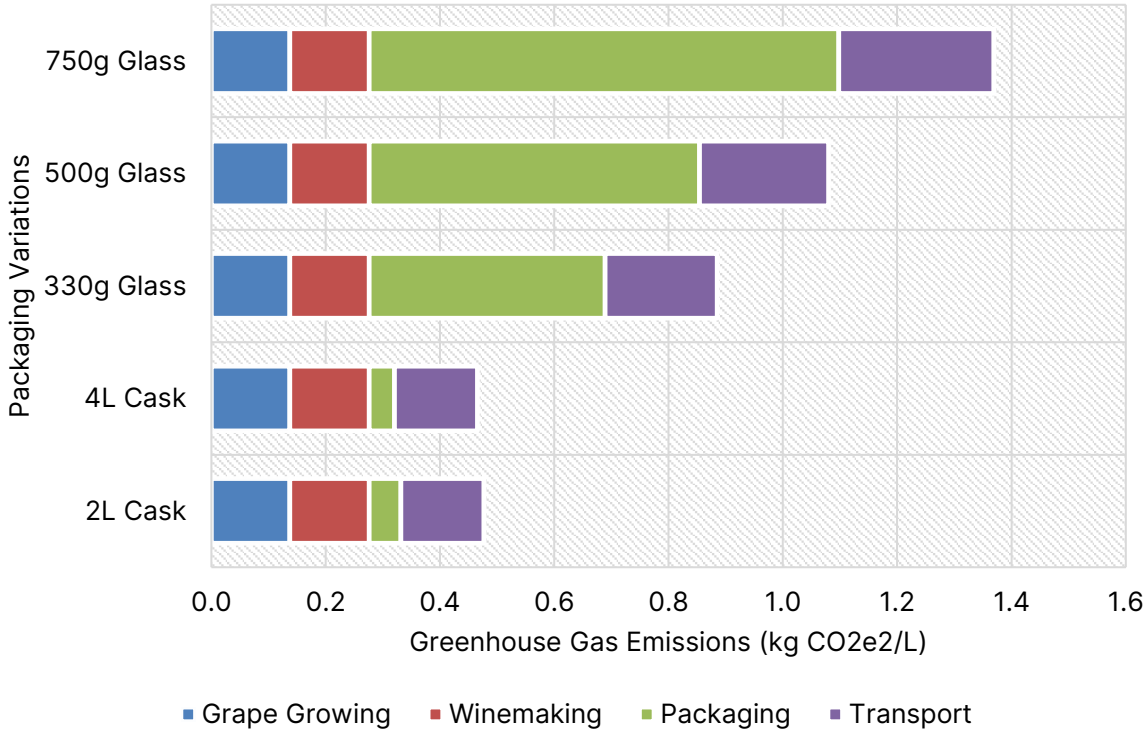


Figure 21: Contribution of GHG emissions of primary categories as influenced by packaging type.

6.5 Biogenic Carbon

This section details the flows of biogenic carbon through the product life cycle, as distinct from fossil carbon. Biogenic carbon exists as part of the short-term carbon cycle; it is involved in processes like photosynthesis by plants, which removes it from the atmosphere; and the subsequent breakdown of organic matter, which re-releases it to the atmosphere. As such, it generally exists in a net zero balance and is not included in overall product emission totals. There are situations where this is not the case, for example carbon storage in wood products, or anaerobic breakdown of organic matter where sequestered carbon is released as methane and other gases. The treatment of these cases is still being refined in LCA. Emissions and absorptions of biogenic carbon have not been included in any totals in this LCA but are discussed here for completeness.

Wine production is heavily based on the biogenic carbon cycle. Grape vines sequester carbon dioxide from the atmosphere and convert it into sugar and biomass which is harvested and transported to the winery. Some of the carbon is converted back to CO_2 during the fermentation process, some remains in the resulting wine, some is converted to CO_2 through breakdown of the liquid waste during wastewater treatment, and the remainder is contained in the grape marc which is treated by a facility and then transported back to the vineyard to be spread as fertilizer and ultimately breaks down, returning to the atmosphere.

There exist requirements that carbon contained in a product and destined for human consumption not be included in the accounting. Additionally, while not included in the scope of the LCA, carbon capture technologies interrelated with fermentation emissions could be a viable opportunity for insetting these short term CO_2 emissions further lowering total footprint of production.

The other significant source of biogenic carbon is in the cardboard cartons used for packaging. Carbon dioxide is sequestered in forests for wood production, from which the cardboard is made. The breakdown of cardboard occurs outside of the system boundary for this LCA.

7. Conclusion

This report focused on updating the 2016 Australian wine industry life cycle assessment in line with current international standards and best practice. The analysis showed that the indicative cradle-to-grave carbon footprint of Australian still wine is 1.05 kg CO2e per L.

Several hotspots were identified that contributed significantly to the greenhouse gas emissions of the product including glass packaging, winery electricity, vineyard diesel use and product distribution. Several strategies were discussed to help reduce these emissions, including further light weighting of bottles, shifting to alternative packing and distribution to export markets in bulk.

The results obtained in this study represent a 10% reduction in emissions for Australian wine comparative to the 2016 study undertaken by the AWRI (1.16kg CO_2e/L). The most significant change between the two models is the penetration of renewable energy sources impacting upon the Australian state and country electricity mix. Increases in the proportions of bulk wine export and glass recycling rate increases within export and domestic markets further drove emissions reductions.

8. References

Abbott, T., Longbottom, M., Wilkes, E., Johnson, D. 2016. Assessing the environmental credentials of Australian wine. *Wine & Viticulture Journal.* 31(1): 35-37.

AgSmart Pty Ltd. 2022. *GrapeWeb Spray Diary Data*. Available from http://www.grapeweb.com.au

Australian Bureau of Statistics (ABS). 2014. *8504.0 - Shipments of Wine and Brandy in Australia by Australian Winemakers and Importers.* Retrieved June, 2014, from https://www.abs.gov.au/ausstats/abs@.nsf/ProductsbyCatalogue/BD58D7790E443352CA2575E70019FF4E?OpenDocument

ABS. 2022. *Agricultural Commodities, Australia*. Available from https://www.abs.gov.au/statistics/industry/agriculture/agricultural-commodities-australia/latest-release

ABS. 2022. *Water Use on Australian Farms.* Available from https://www.abs.gov.au/statistics/industry/agriculture/water-use-australian-farms/latest-release

The Australian Wine Research Institute (AWRI). 2012. *Improving Winery Refrigeration Efficiency.* Retrieved May 12th, 2015, from https://www.awri.com.au/wp-content/uploads/ImprovingRefrigerationEfficiency.pdf

AWRI. 2019. *AWRI Vineyard and Winery Practices Survey.* Available from https://www.awri.com.au/wp-content/uploads/2019/05/AWRI_Practices_Survey_Final_Report.pdf.

AWRI. 2021. How much wine to expect per tonne of grapes?, Ask the AWRI. *Aust N.Z. Grapegrow. Winemake.* 693: 52-53.

Bureau of Meteorology (BOM). 2022 *National Water Account.* Available from http://www.bom.gov.au/water/nwa/2020/index.shtml

BOM. 2022. *Water Information Dashboard.* Available from http://www.bom.gov.au/water/dashboards

BSI. 2012. *PAS 2050-1: 2012 Assessment of life cycle greenhouse gas emissions from horticultural products.* Available from http://www.vegetableclimate.com/wp-content/uploads/2013/10/Horticulture-products-carbon-footprint-New-Zealandsmallpdf.com_.pdf

Clean Energy Council. 2016. *Clean Energy Australia Report.* Available from https://www.cleanenergycouncil.org.au/resources/resources-hub/clean-energy-australia-report

Clean Energy Council. 2022. *Clean Energy Australia Report.* Available from https://www.cleanenergycouncil.org.au/resources/resources-hub/clean-energy-australia-report

Clean Energy Regulator. 2022. *National Greenhouse and Energy Reporting.* Available from https://www.cleanenergyregulator.gov.au/NGER

Department of the Environment. 2022. *Australian national greenhouse accounts – National inventory report 2020, Volume 1*. Available from https://www.dcceew.gov.au/climate-change/publications/national-inventory-report-2020

Department of the Environment. 2022. *National Greenhouse Account Factors –2021.* Available from https://www.dcceew.gov.au/climate-change/publications/national-greenhouse-accounts-factors-2021

Department of the Environment and Energy. 2019. *Assessment of Australian recycling infrastructure – glass packaging updated,* Sustainable Resource Use Pty Ltd , Available from: https://www.agriculture.gov.au/sites/default/files/documents/assessment-australian-recycling-infrastructure-glass-packaging.pdf

Google. 2022. *Google Maps*. Available from www.maps.google.com.au.

Hutton, R., Holzapfel, B., Smith, J., Hutchinson, P., Barlow, K., Bond, W. 2007. *Influence of irrigation and fertiliser management on the movement of water and nutrients within and below the rootzone of vines for sustainable grape production*. Cooperative Research Centre for Viticulture. Retrieved January 22nd, 2016, from https://www.csu.edu.au/__data/assets/pdf_file/0007/453319/KBRHJSBHReport-170907.pdf

International EPD System. 2022. *PCR 2020:06 Wine of fresh grapes, whether or not flavoured; grape must (Version 1.0).* Available from https://www.environdec.com/pcr-library

ISO. 2006. *14040:2006 Environmental management – Life cycle assessment – Principles and framework*. Switzerland: ISO. p.20.

ISO. 2006. *14044: 2006 Environmental management – Life cycle assessment – Requirements and guidelines*. Switzerland: ISO. 46 p.

Murray Darling Basin Authority. 2022. *Water Take Reports under the Basin Plan sustainable diversion limits*. Available from mdba.gov.au

National Water Commission. 2014. *National Performance Report 2012-13: rural water service providers.* Available from http://www.nwc.gov.au/publications/topic/nprs/npr-rural

O-I. 2010. *The Complete Life Cycle Assessment*. Available from http://www.o-i.com/uploadedFiles/Content/Stacked_Content/OI_LCA_031010.pdf.

Rankine, B.C. 1998. *Making good wine: a manual of winemaking practice for Australia and New Zealand*. South Melbourne, Australia: Macmillan Australia. 374p.

Renouf, M. A., Grant, T., Sevenster, M., Logie, J., Ridoutt, B., Ximenes, F., Bengtsson, J., Cowie, A., Lane, J. 2015. *Best Practice Guide for Life Cycle Impact Assessment (LCIA) in Australia*. ALCAS Impact Assessment Committee. Available from https://www.auslci.com.au/Documents/Best_Practice_Guide_V2_Draft_for_Consultation.pdf

SeaRates. 2022. *Distances and Time Calculator*. Retrieved September 8th, 2016, from https://www.searates.com/reference/portdistance/

The Intergovernmental Panel on Climate Change (IPCC). 2007. *Fourth Assessment Report.* Available from https://www.ipcc.ch/assessment-report/ar4/

Vellinga, T. V., Blonk, H., Marinussen, M., Van Zeist, W. J., de Boer, I. J. M., & Starmans, D. 2013. *Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization*. Lelystad, Netherlands: Wageningen UR Livestock Research. 108 p.

Wine Australia. 2019. *National Vintage Report 2019*. Available from https://www.wineaustralia.com/market-insights/national-vintage-report Wine Australia. 2019. *National Vineyard Scan 2019.* Available from https://www.wineaustralia.com/market-insights/national-vineyard-scan

Wine Australia. 2020. *Australian Wine: Production, Sales and Inventory 2018-2019*. Available from https://www.wineaustralia.com/market-insights/australian-wine-production-sales-and-inventory

Wine Australia. 2020. *National Vintage Report 2020*. Available from https://www.wineaustralia.com/market-insights/national-vintage-report

Wine Australia. 2021. *Australian Wine: Production, Sales and Inventory 2020-2021*. Available from https://www.wineaustralia.com/market-insights/australian-wine-production-sales-and-inventory

Wine Australia. 2021. *Australian Wine: Production, Sales and Inventory 2019-2020*. Available from https://www.wineaustralia.com/market-insights/australian-wine-production-sales-and-inventory

Wine Australia. 2021. *National Vintage Report 2021*. Available from https://www.wineaustralia.com/market-insights/national-vintage-report

Wine Australia. 2022. *Export Dashboard Overview*. Available from https://marketexplorer.wineaustralia.com/export-dashboard

Wine Australia. 2022. *National Vintage Report 2022*. Available from https://www.wineaustralia.com/market-insights/national-vintage-report

Wine Grape Council of South Australia. 2019. *2019 SA Winegrape Crush Survey – Full Report.* Available from https://www.wgcsa.com.au/sa-crush--pricing-report.html

Wine Grape Council of South Australia. 2020. *2020 SA Winegrape Crush Survey – Full Report.* Available from https://www.wgcsa.com.au/sa-crush--pricing-report.html

Wine Grape Council of South Australia. 2021. *2021 SA Winegrape Crush Survey – Full Report.* Available from https://www.wgcsa.com.au/sa-crush--pricing-report.html

Wine Grape Council of South Australia. 2022. *2022 SA Winegrape Crush Survey – Full Report.* Available from https://www.wgcsa.com.au/sa-crush--pricing-report.html

Wine Grape Growers Australia. 2013. *National Winegrape Grower Handbook.* Australia: Wine Grape Growers Australia. pg 26-27

Winetitles Media. 2016. *The Australian and New Zealand Wine Industry Directory.* South Australia, Australia: Winetitles Media. Available from www.winetitles.com.au/wine-industry-directory

Winetitles Media. 2020. *The Australian and New Zealand Wine Industry Directory.* South Australia, Australia: Winetitles Media. Available from, www.winetitles.com.au/wine-industry-directory

Winetitles Media. 2021. *The Australian and New Zealand Wine Industry Directory.* South Australia, Australia: Winetitles Media. Available from www.winetitles.com.au/wine-industry-directory

Winetitles Media.2022. *The Australian and New Zealand Wine Industry Directory.* South Australia, Australia: Winetitles Media. Available from www.winetitles.com.au/wine-industry-directory

Appendix A: Vineyard and winery production size and weighting data

Table 30: Regional grower profiles by grower type and vineyard size – winemaking tonnes produced (The National Winegrape Grower Book 2013)

State, Zone, Region	Independent Growers						Winemaker-Grapegrowers						
	<10	>100	10-25	25-50	50-100	Total	<10	>100	10-25	25-50	50-100	Total	Total (Sum)
South Australia	67291	150648	119257	121043	83905	542143	3525	165008	14816	20897	22529	226776	768919
Barossa	6970	9891	12039	12521	10440	51861	689	8492	2869	4796	4891	21738	73599
Far North	70		600	183		853	5		210			215	1068
Fleurieu	5808	20301	8205	8489	12399	55203	895	28578	4141	5315	5091	44020	99222
Limestone Coast	1603	20942	3925	7817	15458	49746	159	46924	2395	3091	5103	57672	107417
Lower Murray	47619	94337	87963	83097	40381	353397	674	74249	2114	2982	2511	82530	435927
Mount Lofty Ranges	5219	5176	6495	8755	5226	30871	1046	6764	3088	4713	4932	20542	51413
The Peninsulas	1		31	181		213	58					58	271
New South Wales	15801	177313	42393	57528	54819	347854	2312	96844	3356	2279	8156	112948	460802
Big Rivers	13574	173204	39071	54159	50003	330011	118	86315	875	366	3260	90934	420945
Central Ranges	543	1602	1197	655	3711	7708	593	9759	828	923	228	12331	20039
Hunter Valley	776		691	1394	685	3545	686	770	1206	621	3725	7009	10555
Northern Rivers	25					25	69					69	94
Northern Slopes	5		81	14		100	123		31	33		187	287
South Coast	95		234	711	351	1391	196		150			346	1737
Southern NSW	772	2508	1118	594	70	5063	486		266	336	943	2031	7093
Western Plains	11					11	41					41	52
Victoria	26215	55704	38323	32406	35426	188074	5681	47576	7861	11218	17344	89680	277754
Central Vic	578	1638	956	1577	1882	6630	895	8259	1451	3718	3707	18030	24661
Gippsland	77	0	135	59	0	271	208	0	103	0	0	312	583
North East Vic	1347	574	2972	1070	2415	8377	1099	5484	1571	1177	1476	10808	19186
North West Vic	22329	51050	31645	26677	29506	161207	1243	33452	2194	3338	9583	49810	211017
Port Phillip	1566	1601	2433	3024	1217	9841	1914	381	2151	2427	1203	8077	17918

Western Vic	318	842	182	0	405	1746	323	0	389	557	1375	2644	4391
Westem Australia	3557	5450	6781	6138	4601	26528	3490	17992	7419	3409	9184	41493	68020
Central Western Australia	31	0	0	0	0	31	41	0	0	0	0	41	72
Eastern Plains, Inland and North	0	0	0	0	0	0	3	0	0	0	3	3	3
Greater Perth	641	0	507	0	0	1148	703	2445	612	276	1296	5333	6481
South West Australia	2863	5450	6274	6138	4601	25327	2742	15546	6806	3133	7888	36116	61442
West Australia South East Coastal	22	0	0	0	0	22	0	0	0	0	0	0	22
Tasmania	455	0	147	155	0	757	971	1375	638	136	1503	4622	5379
Tasmania	455	0	147	155	0	757	971	1375	638	136	1503	4622	5379
Queensland	215	0	47	0	0	262	286	197	150	233	0	866	1128
Queensland	215	0	47	0	0	262	286	197	150	233	0	866	1128
Australian Capital Territory	0	0	0	0	0	0	45	0	0	0	0	45	45
Australian Capital Territory	0	0	0	0	0	0	45	0	0	0	0	45	45

Appendix B: Agrochemical Sprays aggregated from GrapeWeb (AgSmart pty Ltd)

Table 31: Western Australia growers agrochemical use (per ha)

Treatment Product	(kg AI per ha)
Abamectin	0.00
Amitrole	2.50
Azoxystrobin	0.15
Bacillus Amyloliquefaciens Strain	0.04
Boron	0.06
Botanical Oil - Emulsifiable	1.86
Bromoxynil As Octanoate	0.25
Buprofezin	0.12
Calcium	0.46
Canola Oil	1.03
Carfentrazone-ethyl	0.07
Chlorothalonil	1.79
Copper	0.93
Copper (Fertiliser)	181.89
Cyanamide	2.77
Cyflufenamid	0.02
Cyprodinil	0.30
Difenoconazole	0.06
Ethoxylated Octyl Phenol	0.21
Ethyl Methyl Esters Of Vegetable Oil	0.09
Fenhexamid	0.45
Fenpyrazamine	0.50
Fludioxonil	0.20
Glufosinate-ammonium	0.23
Glyphosate	1.33
Humic Acid	1.64
Hydrogen Peroxide	2.03
Indoxacarb	0.05
Kaolin	10.18
Magnesium	0.28
Mancozeb	1.22
Mandipropamid	0.11
Manganese	0.40
Metalaxyl	0.31
Metalaxyl-M	0.09
Metaldehyde	0.40
Metiram	0.84
Metrafenone	0.10
Myclobutanil	0.06

Nitrogen	0.58
Non-ionic Surfactants	0.44
Nonyl Phenol Ethylene Oxide Condensate	0.06
Oxyfluorfen	0.04
Paraffinic Oil	5.13
Paraquat As Dichloride	0.28
Penconazole	0.01
Pendimethalin	4.93
Phosphorus	0.18
Polyalkylene Oxide	0.42
Potassium	0.22
Proquinazid	0.06
Pydiflumetofen	0.03
Pyraclostrobin	0.10
Pyrimethanil	0.62
Pyriofenone	0.09
Quinoxyfen	0.05
Silica	0.85
Spirotetramat	0.05
Spiroxamine	0.25
Sulphur	15.98
Sulphur (Fertiliser)	0.00
Tebuconazole	0.08
Tetraconazole	0.01
Trifloxystrobin	0.08
Trisiloxane Ethoxylate	0.16
Vegetable Oil	1.76
Zinc	0.10

Table 32: Victoria Agrochemical (per ha)

Treatment Product	(kg AI per ha)
Abamectin	0.01
Alcohol Alkoxylate	0.47
Alcohol Ethoxylate	0.14
Ametoctradin	0.22
Amino Acids	0.45
Amisulbrom	0.50
Amitrole	1.08
Ammonium Sulphate	1.55
Ammonium Thiocyanate	0.66
Azoxystrobin	0.15
Bacillus Amyloliquefaciens Strain	0.72
Boron	0.17
Botanical Oil - Emulsifiable	2.84
Buprofezin	0.28
Calcium	0.17
Canola Oil	0.49
Carfentrazone-ethyl	0.05
Chlorantraniliprole	0.02
Chlorothalonil	2.21
Copper	1.61
Copper (Fertiliser)	0.03
Cyflufenamid	0.01
Cyprodinil	0.28
Difenoconazole	0.06
Dimethomorph	0.14
Diquat As Dibromide	0.38
Dithianon	0.42
Emamectin As Benzoate	0.01
Ethoxylated Nonyl Phenol	0.26
Ethoxylated Octyl Phenol	0.25
Ethoxylates	0.28
Ethyl Methyl Esters Of Vegetable Oil	0.69
Fenhexamid	0.45
Fenpyrazamine	0.45
Fluazinam	0.21
Fludioxonil	0.17
Flumioxazin	0.35
Fulvic Acid	0.07
Glufosinate-ammonium	0.76
Glyphosate	1.50
Haloxyfop-p as Methyl	0.24
Hydrogen Peroxide	2.11

Indoxacarb	0.06
Iron	0.10
Kaolin	31.57
Magnesium	0.11
Mancozeb	2.13
Mandipropamid	0.10
Manganese	0.13
Metalaxyl	0.23
Metalaxyl-M	0.12
Methoxyfenozide	0.06
Metiram	1.17
Metrafenone	0.11
Mineral Oil	0.24
Molybdenum	1.53
Myclobutanil	0.04
Nitrogen	2.54
Nonanoic Acid	22.15
Non-ionic Surfactants	0.36
Nonyl Phenol Ethylene Oxide Condensate	0.43
Organosilicone Surf.	0.30
Oryzalin	0.75
Oxyfluorfen	0.07
Paraffinic Oil	3.28
Paraquat As Dichloride	0.52
Penconazole	0.01
Petroleum Oil	7.78
Phosphorous Acid	2.88
Phosphorus	0.08
Potassium	0.18
Potassium Bicarbonate	0.33
Propionic Acid	0.50
Proquinazid	0.05
Pydiflumetofen	0.03
Pyraclostrobin	0.08
Pyrimethanil	0.62
Pyriofenone	0.08
Quinoxyfen	0.05
Seaweed	6.84
Simazine	1.38
Soyal Phospholipids	0.52
Spinetoram	0.03
Spirotetramat	0.05
Spiroxamine	0.27
Sulphur	20.41

Sulphur (Fertiliser)	0.21
Synthetic Latex	0.18
Tebuconazole	0.23
Tetraconazole	0.01
Triadimenol	0.02
Trifloxystrobin	0.08
Trisiloxane Ethoxylate	0.37
Vegetable Oil	0.78
Zinc	0.32
Ziram	0.51

Table 33: South Australia Agrochemical (per ha)

Treatment Product	(kg AI per ha)
Alcohol Alkoxylate	0.24
Alcohol Ethoxylate	0.06
Alkylaryl Polyglycol Ether	0.22
Amitrole	1.00
Ammonium Sulphate	1.72
Ammonium Thiocyanate	0.88
Bacillus Amyloliquefaciens Strain	0.10
Boron	0.12
Botanical Oil - Emulsifiable	1.34
Calcium	0.55
Carbon	0.18
Carfentrazone-ethyl	0.03
Copper	0.72
Cyprodinil	0.30
Dimethomorph	0.18
Diquat As Dibromide	0.37
Dithianon	0.31
Ethoxylated Nonyl Phenol	0.10
Ethoxylated Octyl Phenol	0.10
Ethyl Methyl Esters Of Vegetable Oil	0.70
Glufosinate-ammonium	0.92
Glyphosate	1.25
Haloxyfop-p as Methyl	0.36
Indoxacarb	0.00
Iprodione	0.86
Iron	0.02
Kaolin	16.99
Mancozeb	1.99
Manganese	0.12
Metalaxyl	0.16
Metalaxyl-M	0.09
Metaldehyde	0.18
Myclobutanil	0.40
Nitrogen	26.03
Nonoxynol-9	0.57
Nonyl Phenol Ethylene Oxide Condensate	0.12

Oxyfluorfen	0.05
Paraffinic Oil	0.98
Paraquat As Dichloride	0.52
Petroleum Oil	0.00
Phosphoric Acid	0.40
Phosphorus	0.44
Polyalkylene Oxide	0.14
Polyether Mod. Polysiloxane	0.48
Potassium	0.22
Potassium Bicarbonate	2.52
Proquinazid	0.07
Quinoxyfen	0.06
Simazine	1.80
Soyal Phospholipids	0.20
Sulphur	4.57
Sulphur (Fertiliser)	0.11
Tebuconazole	0.03
Triadimenol	0.10
Trisiloxane Ethoxylate	0.25
Vegetable Oil	0.47
Zinc	0.09

Table 34: New South Wales grower agrochemical use (per ha)

Treatment Product	(kg AI per ha)
Alcohol Alkoxylate	0.30
Alcohol Ethoxylate	0.03
Ammonium Sulphate	1.09
Bacillus Amyloliquefaciens Strain	0.07
Canola Oil	0.31
Carfentrazone-ethyl	0.03
Copper	0.77
Copper (Fertiliser)	6.00
Diquat As Dibromide	0.36
Dithianon	0.35
Emamectin As Benzoate	0.00
Ethoxylated Nonyl Phenol	0.05
Ethoxylated Octyl Phenol	0.12
Ethyl Methyl Esters Of Vegetable Oil	0.95
Glufosinate-ammonium	0.63
Glyphosate	1.99
Hydrogen Peroxide	1.93
Iprodione	0.60
Mancozeb	2.42
Metalaxyl	0.27
Metalaxyl-M	0.19
Myclobutanil	0.04
Nitrogen	0.22
Nonyl Phenol Ethoxylate	0.29
Nonyl Phenol Ethylene Oxide Condensate	0.29
Oxyfluorfen	0.06
Paraquat As Dichloride	0.81
Phosphoric Acid	0.27
Phosphorous Acid	2.39
Phosphorus	0.15
Polyalkylene Oxide	0.21
Potassium	0.20
Propionic Acid	0.42
Proquinazid	0.04
Soyal Phospholipids	0.37
Sulphur	3.58
Trisiloxane Ethoxylate	0.28