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# Carbon footprint in Austrian viticulture – Evaluation of the main polluters and possible solutions in entire the production chain

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**Abstract.** This study examines the carbon footprint of Austrian viticulture, with a focus on grape suppliers and wine producers across different regions. The analysis highlights key contributors to emissions, including vineyard replanting, grape production, wine production, using the certification data "Sustainable Austria" from the years 2022 and 2023. The findings reveal regional differences in emissions, with Burgenland, Lower Austria, Styria, Vienna and Carinthia, particularly in grape production. Notably, emissions from vineyard replanting remained consistent across all operation sizes, while grape production and packaging showed significant variation. Larger wineries benefited from economies of scale, displaying lower emissions per unit compared to smaller wineries. However, emissions related to small units (glass bottles…) and packaging remain critical areas for improvement, contributing a substantial portion of the total carbon footprint. The study underscores the need for continued sustainability efforts, particularly in optimizing packaging practices and supporting smaller wineries in reducing their carbon footprint.

## 1. Introduction

The Austrian wine industry plays a crucial role in the country's economy and cultural landscape. However, as many other agricultural sectors, wine production is associated with environmental impacts, particularly in the form of greenhouse gas (GHG) emissions. In the light of increasing global attention to sustainability and climate change, understanding and reducing the carbon footprint of viticulture has become an essential focus for both industry and policymakers. Climate change is not only a pressing global issue but also a direct threat to wine production, influencing everything from grape growing conditions to long-term vineyard sustainability.

The "Sustainable Austria" certification program is designed to promote sustainability in Austrian wine production, covering ecological, economic, and social criteria. The program evaluates over 380 activities in the vineyard and winery. Since 2022, the certification tool has included a carbon footprint calculator. This tool is integrated into the online certification platform, enabling certified wineries to continuously improve their sustainability performance.

This study builds upon previous research, including the 2023 study conducted by Poelz and Rosner [1], and represents a comprehensive update of the Life Cycle Analysis (LCA) of the Austrian wine industry. With a renewed focus on data collected by "Sustainable Austria", this evaluation aims to analyse the carbon footprint of Austrian wine production across the entire value chain, following best-practice standards as defined by international norms such as 14040:2021, ISO 14044:2021 an ISO 14067:2018 [2].

The carbon footprint in viticulture is influenced by various factors throughout the entire production chain, including vineyard planting but also the use of fertilizers and pesticides, energy consumption, enological agents, packaging materials, and transportation. In Austrian wine production, specific practices, such as organic production and soil management in vineyards, the energy-intensive winemaking processes, and the usage of light-weighted and refilling of glass bottles, have been identified as significant factors in the industry's GHG emissions [1].

This study focuses on identifying the main drivers of emissions within the primary stages of vineyard planting, grape production, winemaking, and packaging while excluding distribution (cradle-to-gate approach).By evaluating the carbon emissions from these key areas, these analyses seek to highlight the primary polluters and propose potential solutions for reducing emissions across the wine production sector.

The findings will provide critical information for the Austrian wine and viticulture sector, helping to identify areas with the greatest potential for emission reductions and improvements. Additionally, the study will offer insights into how different production practices, such as organic versus conventional methods, affect GHG emissions, thereby supporting the industry's efforts to transition to more sustainable practices. The ultimate goal is to help the sector reduce its carbon footprint, contribute to the global fight against climate change, and ensure the long-term viability of Austrian viticulture in an increasingly challenging climate.

## 2. Materials and methods

### 2.1. Study design and data collection

This study compares the carbon footprints of Austrian wineries for the 2022 and 2023 vintages. The analysis is based on data from sustainability certification "Sustainable Austria," which has been available in an online version for 10 years and now covers over 26.6% of the Austrian wine-growing area. Since the 2022 harvest, "Sustainable Austria" has automatically calculated the carbon footprint for each winery based on various metrics, including vineyard acreage, and wine, both in bulk as well as in 0.75-litre bottles. The data collection includes both, fully certified wine producers and grape suppliers. For grape suppliers, where direct carbon footprint calculations are not available, manual calculations are performed based on the logic applied to entire operations.

The data for 2023 are preliminary and incomplete, as not all wineries had submitted their information and completed certification at the time of this study. Approximately 28 wineries, equivalent to a growing area of around 554 hectares, are still pending by 31st of August 2024.

### 2.2. Variables and parameters

The primary variables analysed in this study include:

- operational types: Distinction between wineries certified for the wine producers and grape suppliers.
- regional differences: Comparison of carbon footprints across different Austrian wine-growing regions.
- operating resources: Analysing the use of fuel, use of plant protection products, energy consumption (quantities and sources), treatment measures and the use of glass bottles and packaging (cardboard cases and screw caps).

### 2.3. Analytical methods and software tools

The carbon footprint data are calculated using the "Sustainable Austria" online tool and analysed with Microsoft Excel. The tool provides detailed $CO_2$-balances for vineyard replanting, grape production, and wine production. For a more precise analysis, wine production is broken down into specific sub-areas, such as small units and packaging. This detailed breakdown enables a more precise assessment of the carbon footprints associated with the individual production steps.

For the grape suppliers, $CO_2$-balance calculations are performed manually, based on the consumption data entered, multiplied by the specified emission values, based on the logic for wine producers, utilizing average yield data from Statistics Austria.

This process enables the creation of comparable figures across different winery sizes and production methods.

### 2.4. Software and tools

The $CO_2$-balances for vineyard replanting, grape production, and wine production are calculated using the "Sustainable Austria" system. In order to enable a more precise analysis of the wine production sector, which is further broken down into specific sub-areas. This detailed breakdown enables a more precise assessment of the carbon footprints associated with the individual production steps.

Manual calculations and evaluations were conducted in Microsoft Excel, particularly for the $CO_2$-balances of grape suppliers, where the data were derived based on the logic used for wine producers and using average yield values from Statistics Austria to create comparable figures.

### 2.5. Ethical considerations

As the study is based on anonymized data, no explicit ethical approval is required. All applicable data protection complies with the regulations, and the results are presented in a way that prevents any identification of individual wineries.

### 2.6. Functional unit and system boundaries

#### 2.6.1. Functional unit and system boundaries

The functional units, which serve as the basis for all results reported in this study, are defined as:

- hectares of vineyard
- kilogram of grapes
- litres of bulk wine
- 0.75-litre bottles

In the context of this paper, small units (e.g. bottles, bag-in-box, steel containers (KEG)…) are defined as units with a maximum capacity of 60 litres.

These functional units are chosen to capture the variability in the size and production volumes of Austrian wineries and to provide a standardized basis for comparing the carbon footprints of different production processes and packaging sizes.

This approach ensures consistency when comparing emissions or other metrics across different packaging formats and production scales.

The system boundaries of this analysis include:

- Grape growing phase: This phase accounts for use (Scope 1 and Scope 2) and indirect emissions (Scope 3) of all inputs to the process including depreciation and amortisation reaching from the vineyard planting to all management activities during the vegetation period.
- Winemaking phase: This phase includes the emission profiles for onsite electricity use, combustion of fuels and gases for processing, enrichment, filtration and fining additives for winemaking as well as cleaning agents. Depreciation of storage tanks and machinery is not included.

#### 2.6.2. Impact Category

The impact category used in this study is Greenhouse Gas Emissions, measured in kg $CO_2$-equivalents (kg $CO_2e$).

#### 2.6.3. Model and Calculation Approach

The model calculates the average carbon footprint for Austrian wine (cited in section 2.4) using average values for four different categories of winery sizes to capture scale effects:

- Very small wineries: These wineries have a vineyard area of less than 10 hectares representing a relatively low production volume and limited vineyard area.
- Small wineries: These wineries have a vineyard area between 10 and 30 hectares. They have moderate production capacity.
- Medium-sized wineries: These wineries have a vineyard area between 30 and 80 hectares. They can offer in specialised wine shops but also in super markets.
- Large wineries: These wineries have a vineyard area of over 80 hectares. They dominate the industry and are the main representatives in super markets.

By segmenting wineries into these size categories, the study aims to analyse differences in carbon emissions based on operational scale.

## 3. Results and discussion

### 3.1. Data overview

The Austrian wine industry has shown progress in sustainable wine production under the "Sustainable Austria" certification program

The current data from the "Sustainable Austria" certification program show that a total of 508 (2023: 630) entities have been certified in 2022. This includes 360 (2023: 453) wine producers (entire production) and 148 (2023: 177) entities that have become certified as grape suppliers.

In 2022, out of the total 2.5 million litres [3-4] of wine produced in Austria, 20.5% were certified as sustainable. By 2023, the total production decreased to 2.3 million litres [5-6], but the share of certified wine increased to 22.5% produced under the certification.

The total wine-growing area in Austria decreased slightly from 44,537 hectares [3-4] in 2022 to 44,210 hectares [5-6] in 2023. However, the area certified according to the "Sustainable Austria" program increased from 25.9% in 2022 to 27.6% in 2023.

This demonstrates a growing commitment to sustainability despite an overall decrease in production volume and wine-growing area.

In 2022, a total of 508 wineries produced 0.5 million litres of wine on 11,105.33 hectares of wine certified as “sustainable”. Burgenland contributed 11.3 million litres from 2,986 hectares, while Lower Austria was strongly represented with 34.6 million litres from 6,781 hectares. Styria produced 4.8 million litres from 1,162 hectares.

In 2023, the number of certified wineries rose to 630, producing 0.5 million litres from 11,759.34 hectares. Lower Austria remains the largest producing region with 36.4 million litres from 7,485 hectares, followed by Burgenland and Styria.

Wine traders are not allocated to a specific region, as they operate across all regions, adding an additional 0.3 million (2023: 0.3) litres to the Sustainable Austria certification.

The total $CO_2$-emissions from *grape suppliers* are composed of 33% (2022 and 2023) from vineyard replanting and 67% (2022 and 2023) from grape production (see Figure 1):

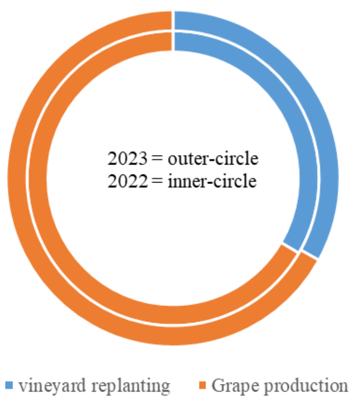


**Figure 1.** Consumption based $CO_2$-emissions of grape suppliers.

The total CO2-emissions from *wine producers* are composed of the following and are depicted in Figure 2:

- 5% (both years) from vineyard replanting, reflecting the emissions associated with replanting vineyard areas.
- 12% (2023: 13%) from grape production, covering the emissions generated during the cultivation and harvesting of grapes.
- 13% (both years) from wine production, representing the emissions from the winemaking process itself.

- 53% (2023: 52%) from small units (small containers), which represent the largest share of emissions due to packaging in smaller formats.
- 17% (both years) from packaging, accounting for the emissions from packaging materials and processes.

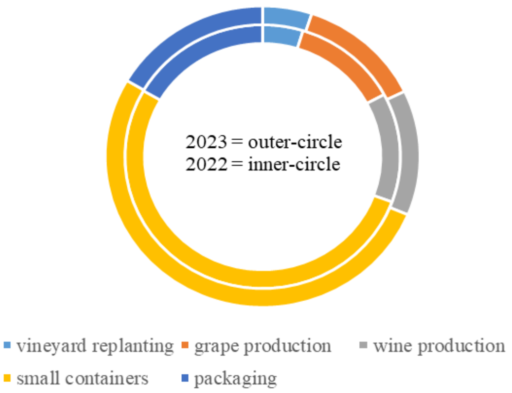


**Figure 2.** Consumption based $CO_2$-emissions of wine producers.

The overall analysis of the life cycle assessment by Ferrara and De Feo [7] concludes that both the viticulture sector (vineyard replanting and grape production) and the primary packaging production sector (glass bottles) are among the hotspots. This is also reflected in the analysis of the following data.

## 3.2. Grape production by grape suppliers

This section examines the carbon footprint associated with grape suppliers, who do not produce wine, broken down into the key areas of new vineyard planting and grape production. Table 1 provides an overview of the average kg $CO_2e$ for these areas in the years 2022 and 2023.

**Table 1.** Average kg $CO_2e$ for grape suppliers.

| production steps | 2022 in kg CO2e | 2023 in kg CO2e |
|---|---|---|
| vineyard replanting / ha | 343.12 | |
| grape production / ha | 718.60 | 743.42 |
| Average total CO2-emissions for a 10-hectare-winery | 10,248 | 10,371 |
| Average total CO2-emissions/ ha for a 10-hectare-winery | 950.51 | 1,095.67 |

The most significant contributor to the carbon footprint in the category *grape production* for grape suppliers is the use of **conventional fuel** (diesel, gasoline) (2022: 75%; 2023: 74%). This underscores the heavy reliance on traditional fuel sources in grape production operations.

The use of **fungicides** remained constant at 15% in both 2022 and 2023, indicating a steady reliance on these agents to control fungal diseases in vineyards.

The use of **insecticides** has decreased from 1% in 2022 to 0% in 2023 proportion of wineries that renounce insecticide is negligible. These plant protection results also shows the great awareness of the certified to manage without insecticides.

**Adequate planting/green manuring** remains at 4%, while the use of **fertilizers** increase slightly, from 6% in 2022 to 7% in 2023. (see Appendix 1)

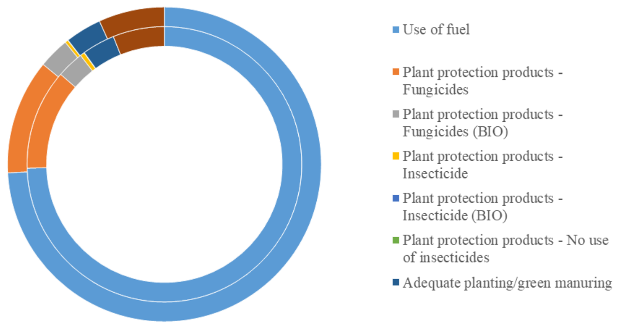


**Figure 3.** Consumption based $CO_2$-emissions of grape production by grape suppliers.

## 3.3. Grape production by wine producers

The calculation of the carbon footprint for a wine producer encompasses a comprehensive view, including not only the planting of new vineyards and amortisation and depreciation, respectively, in grape production, but also the process of wine production itself. The Sustainable Austria Tool aggregates these components to provide a total carbon footprint value for the operation. However, in order to offer a more expressive insight into the specific impacts of wine production, the data has been further categorized into subgroups, specifically small units and packaging. This approach allows for a more detailed understanding of the different elements contributing to the overall emissions. Table 2 presents the average kg $CO_2e$ for these subcategories for the years 2022 and 2023.

**Table 2.** Average kg $CO_2e$ for wine producers.

| production steps | 2022 in kg CO2e | 2023 in kg CO2e |
|---|---|---|
| vineyard replanting / ha | 343.12 | |
| grape production / ha | 899.67 | 851.29 |
| wine production / ha | 706.02 | 610.24 |
| | | |
| small units / 0.75-l bottle | 0.34 | 0.33 |
| packaging / 0.75-l bottle | 0.11 | 0.11 |
| winery carbon footprint / kg grape * | 1.11 | 1.00 |
| winery carbon footprint / litre bulk wine ** | 0.55 | 0.54 |
| winery carbon footprint / 0.75-l bottle *** | 0.70 | 0.70 |

* According to the harvest declaration

** Quantity of wine; must sold in unsealed containers in the wine year

*** Volume of wine sold in small units in the wine year (minus additional purchases of bottled goods)

The most significant contributor to the carbon footprint in *grape production* by wine producers is the use of

**conventional fuel** (diesel and gasoline), which accounts for 75% in both years. This highlights the heavy reliance on traditional fuel sources in vineyard operations.

Plant protection products also play a significant role in viticulture, particularly in safeguarding crops from diseases and pests. **Fungicides** are among the most commonly used agents, accounting for 12.7% of total plant protection product usage, with a slight increase to 13.3% in 2023. Their use is essential in combating fungal diseases that can severely affect grape quality and yield.

In contrast, the use of **insecticides** remains consistently low, comprising just 0.3% of plant protection efforts, even decreasing to 0.2% in 2023. (see Appendix 1) This reflects a broader trend towards minimizing chemical inputs in pest management. Notably, many wineries have eliminated the use of insecticides, with 0.0% usage reported in both years, highlighting a growing commitment to more sustainable and environmentally friendly practices in the industry. (see Appendix 1) This shift aligns with the increasing focus on biodiversity and ecosystem health in vineyard management.

Adequate **planting and green manuring** practices have remained stable at 3%, indicating a consistent focus on soil health and sustainability in vineyard management. These practices are crucial for maintaining soil structure, enhancing nutrient content, and promoting biodiversity, contributing to the long-term health of the vineyards.

In contrast, **fertilizer** use has seen a slight decline, dropping from 9% in 2022 to 8% in 2023. (see Appendix 1) This reduction suggests a shift towards more efficient nutrient management strategies and a growing awareness of the environmental impacts of over-fertilization.

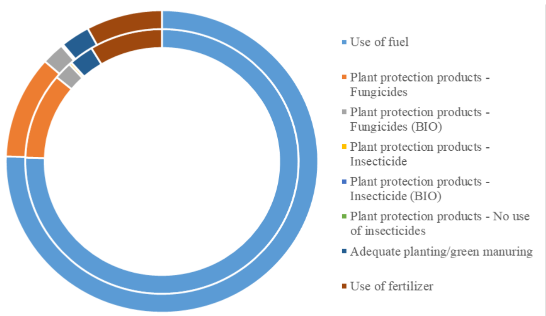


**Figure 4.** Consumption based $CO_2$-emissions of grape production by wine producers.

## 3.4. Wine production by wine producers

The most significant contributor to the carbon footprint in *wine production* is **enrichment**, which accounts for 27.9% (2023: 25.0%) of the total measures, and the **total energy use** 29.7% (2023: 28.0%) (in particular energy source gas, which makes up 13.8% (2023: 13.9%) and renewable energies (e.g. photovoltaics, solar thermal energy, ambient heat, wind and hydropower) with 3.4% (2023: 3.2%)). The addition of **carbonic acid snow** for mash temperature control for white/rosé wine contributes 12.2% (2023: 16.2%) to the overall emissions.

Other factors such as the mark-ups for **cellar cleaning** (2022: 3.4% and 2023: 3.5%) and **composting** (2022: 5.5% and 2023: 5.7%) play a role, although they have a smaller overall impact.

The $CO_2$-emissions for treatment measures remained stable at around 21%. (see Appendix 1)

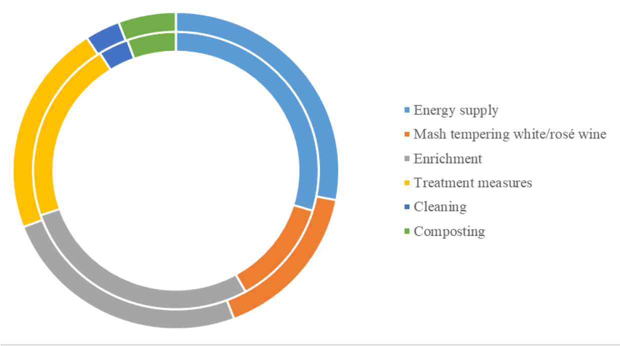


**Figure 5.** Consumption based CO2-emissions of wine production by wine producers.

From the detailed illustration of the life cycle footprint of a wine bottles (0.75 l) by Pinto da Silva and Esteves da Silva [8] and Hirlam et al. [9], it is clear that the energy production accounts for the largest part of wine production. This is also reflected in the analysis of the data of Sustainable Austria.

## 3.5. Small units by wine producers

Looking at the various *small units* (in litres, only possible for 2023, as no information on the usage of new glass was available for 2022), it becomes clear that 20% of these units are refilled (15% in glass bottles, 5% in stainless steel tanks (KEG), while 80% are new units. These new units are categorized into three main groups: new glass, PET and bag-in-box. New glass makes up the largest portion at 78%, followed by PET at 2% and bag-in-box at 0.2%. This distribution highlights the reliance on new glass units for wine packaging, with only a small percentage dedicated to reusable options.

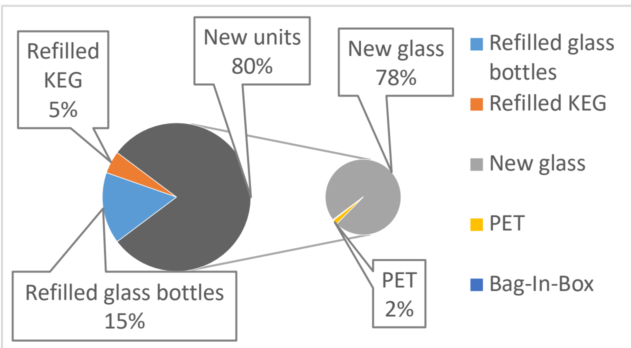


**Figure 6.** Breakdown of small units in litre in 2023.

**Table 3.** Small units components by litre and kg $CO_2e$ in 2022 and 2023.

| 2022 | million litres | kg $CO_2e$ emissions | kg $CO_2e$ / litre |
|---|---|---|---|
| new glass in kg glass weight | 45.9 | 35,642,424.37 | 0,7764 |
| Tetra Pak/soft packs | 0.0 | 0.0 | 0,1555 |
| PET/plastic hard packaging | 7.4 | 948,672.15 | 0,1288 |
| bag-in-box | 0.5 | 904.97 | 0,0017416 |
| cans | 0.0 | 0.0 | 2,3923 |
| KEG (steel container) | 2.9 | 17,102.93 | 0,00588 |
| **2023** | **million litres** | **kg $CO_2e$ emissions** | **kg $CO_2e$ / litre** |
| new glass in kg glass weight | 44.4 | 34,440,430.04 | 0,7764 |
| Tetra Pak/soft packs | 0.0 | 0.0 | 0,1555 |
| PET/plastic hard packaging | 6.7 | 860,470.42 | 0,1288 |
| bag-in-box | 0.5 | 928.43 | 0,0017416 |
| cans | 0.02 | 4,784.60 | 2,3923 |
| KEG (steel container) | 3.9 | 22,768.80 | 0,00588 |

**The overwhelming majority of the carbon footprint in the section *small units* is attributed to the use of new glass (calculated as new glass kg glass weight), which accounts for 97.4% (2023: 97.5%) of the total small units $CO_2$-emissions (see**

Table 3). From the detailed illustration of the life cycle footprint of a wine bottle (0.75-litre) by Pinto da Silva and Esteves da Silva [8] and Hirlam et al. [9], the glass production accounts for the largest part of bottling and packaging. This can also be clearly seen in the analysis of the data from Sustainable Austria

It should be positively noted that the use of lightweight glass bottles (defined as 0.75-litre-bottles) increased from 48% in 2022 to 69% in 2023. Detailed information on regional differences can be found in Chapter 3.7, Table 8.

Other small unit types, such as **PET**/plastic hard packaging, contribute minimally, representing only 2.6% (2023: 2.4%) to the total emissions. Interestingly, alternative units options such as **Tetra Pak**/soft packs, **bag-in-box** and **cans** are not utilized at all (0.0% for each). KEG (steel containers) accounted for 0.0% to 0.1% in 2023. (see Appendix 1)

In summary, the use of new glass dominates the carbon footprint in the small unit category, with very little contribution from more sustainable or alternative packaging options.

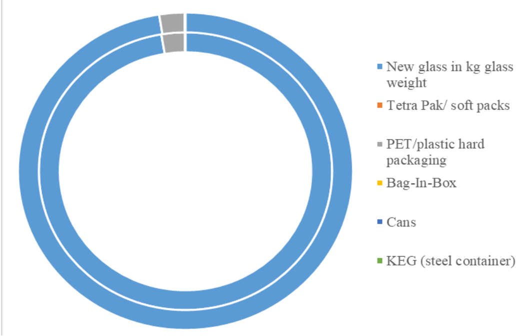


**Figure 7.** Consumption based $CO_2$-emissions of small units by wine producers.

## 3.6. Packaging by wine producers

**Table 4.** Packaging components by litre and kg $CO_2e$ in 2022 and 2023.

| 2022 | Mio. litres | kg $CO_2e$ emissions | kg $CO_2e$ / litre |
|---|---|---|---|
| natural cork | 5.1 | 35,952.68 | 0,007 |
| plastic closures | 2.9 | 40,995.43 | 0,0142 |
| glass closures | 0.7 | 65,461.32 | 0,09741 |
| screw caps | 82.9 | 6,462,706.17 | 0,078 |
| crown caps | 3.0 | 19,164.25 | 0,00644 |
| crates | 5.3 | 5,130.73 | 0,00097 |
| cardboard < 50% recycled content | 17.8 | 1,382,043.28 | 0,07760 |
| cardboard > 50% recycled content | 68.2 | 3,176,288.05 | 0,04657 |
| mark-up labels | 97.8 | 371,691.58 | 0,0038 |
| **2023** | **Mio. litres** | **kg $CO_2e$ emissions** | **kg $CO_2e$ / litre** |
| natural cork | 5.5 | 38,718.01 | 0,007 |
| plastic closures | 2.4 | 34,195.13 | 0,0142 |
| glass closures | 0.5 | 51,830.75 | 0,09741 |
| screw caps | 81.3 | 6,343,177.42 | 0,078 |
| crown caps | 3.3 | 21,240.72 | 0,00644 |
| crates | 6.3 | 6,071.35 | 0,00097 |
| cardboard < 50% recycled content | 16.1 | 1,248,527.18 | 0,07760 |
| cardboard > 50% recycled content | 66.8 | 3,108,942.16 | 0,04657 |
| mark-up labels | 97.5 | 370,480.86 | 0,0038 |

The most significant contributor in the *packaging* category as shown in Appendix 1 is the use of **screw caps**, which accounts for 55.9% (2023: 56.5%) of the total packaging impact. This indicates that screw caps are the predominant closure method used in wine packaging.

**Cardboard packaging** also plays a substantial role; particularly with cardboard containing at least 50% recycled content, which represents 27.5% (2023: 27.7%) of the packaging materials. Cardboard with less than 50% recycled content contributes an additional 12.0%. (2023:

11.1%) This highlights the importance of recycled materials in the overall packaging footprint.

Other components, such as **plastic and glass closures**, have a minimal impact, contributing 0.4% (2023: 0.3%) and 0.6% (2023: 0.5%), respectively. **Natural cork closures** are used even less, making up only 0.3% (in 2022 and 2023), while **crown caps** contribute just 0.2% (in 2022 and 2023). **Crates** are not used at all in 2022, but amount to 0.1% in 2023.

The **labels** add a small but notable 3.2% (2023: 3.3%) to the total packaging impact.

In summary, screw caps and recycled cardboard packaging are the dominant elements in the wine packaging process, while other materials like cork and plastic stoppers play a minor role.

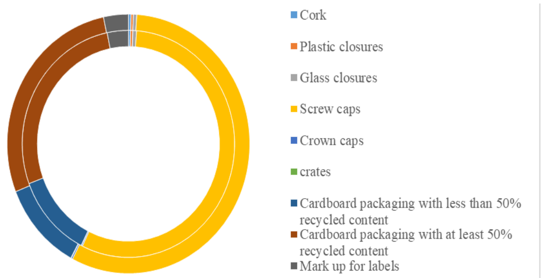


**Figure 8.** Consumption based $CO_2$-emissions of packaging by wine producers.

## 3.7. Regional differences

In addition to the primary analysis, a key objective of this work is to identify and evaluate regional differences in average $CO_2$-emissions across the Austrian wine industry.

When examining the data related to grape suppliers, it is important to note that the scope of this analysis is somewhat limited, as the data is restricted to just three federal states. Despite this limitation, the insights gained from these regions will provide valuable information on how different geographic and climatic conditions, as well as regional practices, influence the carbon footprint of grape production. This analysis will help pinpoint areas with the highest emissions and identify opportunities for improvement tailored to each region's unique characteristics, but also allows conclusions to be drawn about vintage influences.

**Table 5.** Regional differences in average kg $CO_2e$ emissions for grape suppliers per hectare.

| 2022 | vineyard replanting | grape production |
|---|---|---|
| Burgenland (n = 86) | 343.12 | 675,68 |
| Lower Austria (n = 61) | | 777,90 |
| Styria (n = 1) | | 792,64 |
| **2023** | **vineyard replanting** | **grape production** |
| Burgenland (n = 85) | 343.12 | 679,53 |
| Lower Austria (n = 90) | | 800,08 |
| Styria (n = 2) | | 908,94 |

The increase in $CO_2$-emissions from grape production in Lower Austria and Styria can be attributed to the rise in the number of grape suppliers in these regions. However, the increase in emissions does not directly correspond to the growth in the number of businesses. In Lower Austria, grape production emissions rose from 777.90 kg $CO_2e$ in 2022 to 800.08 kg $CO_2e$ in 2023, while in Styria, emissions jumped from 792.64 kg $CO_2e$ to 908.94 kg $CO_2e$, indicating greater intensity per hectare despite the increased number of suppliers. This increase can be attributed to vintage-specific conditions, as growers had to apply more plant protection treatments and perform additional soil management due to the weather conditions, which contributed to higher $CO_2$-emissions.

This section delves into the regional differences in the carbon footprint across **wine producers**, focusing on key areas such as vineyard replanting, grape production, wine production, packaging, and small units. The list below presents the average kg $CO_2e$ values for these activities across different Austrian regions for 2022 and 2023:

**Table 6.** Regional differences in average kg $CO_2e$ emissions for wine producers per hectare.

| 2022 | vineyard replanting | grape production | wine production |
|---|---|---|---|
| Burgenland (n = 66) | 343,12 | 782,96 | 391,54 |
| Lower Austria (n = 228) | | 900,64 | 843,41 |
| Styria (n = 53) | | 1 050,79 | 564,31 |
| Carinthia (n = 3) | | 668,93 | 274,74 |
| Vienna (n = 5) | | 932,83 | 353,18 |
| **2023** | **vineyard replanting** | **grape production** | **wine production** |
| Burgenland (n = 64) | 343,12 | 752,83 | 404,46 |
| Lower Austria (n = 322) | | 863,83 | 659,69 |
| Styria (n = 51) | | 903,54 | 584,61 |
| Carinthia (n = 5) | | 684,08 | 320,08 |
| Vienna (n = 5) | | 937,66 | 610,87 |

– Burgenland grape production emissions slightly decreased, and wine production emissions rose from 391.54 kg $CO_2e$ to 404.46 kg $CO_2e$.
– Lower Austria grape production emissions dropped from 900.64 kg $CO_2e$ to 863.83 kg $CO_2e$, but with a much larger increase in the number of wineries.
– Styria grape production emissions decreased from 1,050.79 kg $CO_2e$ to 903.54 kg $CO_2e$, indicating improved efficiency.
– Carinthia and Vienna had minor variations in emissions despite small business numbers.

The conclusion indicates that wine producers consistently invest more in vineyard management compared to grape suppliers in order to maintain high-quality standards. Each year, wine producers tend to engage in more intensive practices, such as additional plant protection measures, soil management, and other vineyard interventions. This increased effort is driven by their focus on producing premium wines, resulting in higher $CO_2$-emissions per hectare compared to grape suppliers, who may focus more on yield rather than on intensive quality measures.

The regional differences in wine production for *small units* already produced are shown in Table 7.

**Table 7.** Regional differences in average kg $CO_2e$ emissions for wine producers per 0.75-litre-bottle.

| 2022 | small units | packaging |
|---|---|---|
| Burgenland (n = 66) | 0,41 | 0,12 |
| Lower Austria (n = 228) | 0,30 | 0,11 |
| Styria (n = 53) | 0,41 | 0,13 |
| Carinthia (n = 3) | 0,47 | 0,10 |
| Vienna (n = 5) | 0,37 | 0,09 |
| **2023** | **small units** | **packaging** |
| Burgenland (n = 64) | 0,38 | 0,11 |
| Lower Austria (n = 322) | 0,31 | 0,11 |
| Styria (n = 51) | 0,38 | 0,13 |
| Carinthia (n = 5) | 0,47 | 0,09 |
| Vienna (n = 5) | 0,37 | 0,10 |

**Table 8.** Regional differences in lightweight glass usage expressed as a percentage of total new glass volume.

| lightweight glass bottles | 2022 | 2023 |
|---|---|---|
| Burgenland | 54% (n = 66) | 59% (n = 64) |
| Lower Austria | 56% (n = 228) | 49% (n = 320) |
| Styria | 12% (n = 53) | 17% (n = 51) |
| Carinthia | 25% (n = 3) | 15% (n = 5) |
| Vienna | 37% (n = 5) | 41% (n = 5) |

In Lower Austria, despite the increase in the number of businesses from 228 in 2022 to 322 in 2023, emissions per 0.75-litre-bottle remained relatively stable, with small unit emissions at 0.30 kg $CO_2e$ in 2022 and 0.31 kg $CO_2e$ in 2023, and packaging emissions unchanged at 0.11 kg $CO_2e$. A significant factor contributing to this stability is the decrease in the share of lightweight glass bottles. In 2022, 56% of the bottles used were lightweight glass, but this figure dropped to 49% in 2023. One key reason for this decline is the availability of bottles. During the COVID-19 crisis, many wineries stocked up on bottles or opted for those that were more readily available, which were not necessarily lightweight glass.

In Carinthia, the number of businesses increased from 3 in 2022 to 5 in 2023, yet the emissions remained consistent for small units at 0.47 kg $CO_2e$. Packaging emissions slightly decreased from 0.10 kg $CO_2e$ in 2022 to 0.09 kg $CO_2e$ in 2023. This reduction in packaging emissions is linked to the decline in the use of lightweight glass bottles, which dropped from 25% in 2022 to 15% in 2023, contributing to improved packaging efficiency despite the growing number of wineries.

### 3.8. Average yield per hectare

An important parameter that has a significant impact on wine production is the maximum yield per hectare. However, the yield that a winery achieves is highly dependent on the conditions specific to the vintage and type of management (organic or not). In particular, the climatic conditions of a particular growing season have a decisive influence on the development of the vines, such as flowering, grape and berry formation. As a result, annual yields can vary considerably. These differences in yield have a significant impact on the greenhouse gas emissions per 0.75-l bottle or litre of bulk wine, as the effort required in many areas, such as vineyard management or grape harvesting, is independent of the quantity harvested. [1]

According to Statistics Austria, the 5-year average yield in Lower Austria is 5,380 litres per hectare [1].

A comparison of the available data for the wine producers (harvest quantity according to the harvest declaration divided by the grape production area gives the average yield per hectare) compared to the data from Statistics Austria is depicted in Table 9:

**Table 9.** Comparison of average yields per hectare of wine producers.

| Wine producers | 2022 | 2023 |
|---|---|---|
| by conventional wine producers according to the harvest declaration | 4,664.08 | 4,279.66 |
| by organic wine producers according to the harvest declaration | 4,270.84 | n/a* |
| in Austria according to Statistics Austria | 5,899.30 | 5,471.90 |

* not available at the time of publication

The data show that the yields according to Statistics Austria (2022 and 2023) tend to be higher than the yields that emerge directly from the certified sustainable wineries' harvest reports. This is driven by a general focus on quality and sustainability within the Austrian wine industry. Producers, regardless of their method of cultivation, often intentionally maintain lower yields to enhance grape quality, which is reflected in the average yield per hectare.

A key distinguishing factor between wine producers is the difference between organic and conventional wine production. When comparing the data from 2022 (2023 is not available at the time of publication), organic wine producers have an average yield of 4,270.84 litres/ha with 1,295.51 kg $CO_2e$ per hectare, across 72 wineries, while conventional producers yield 4,664.08 litres/ha with 1,229.38 kg $CO_2e$ per hectare, across over 288 wineries.

The higher emissions in organic wine production are largely attributed to the unique challenges faced by organic producers. Organic vineyards require more frequent plant protection measures and intensive soil management due to the lack of synthetic chemicals, which can increase the need for repeated interventions such as mechanical weeding, compost application, and additional labour.

## 3.9. Economy of scale

In order to make well-founded statements regarding the economy of scale in connection with GHG emissions, the wineries are categorised into specific clusters. For this purpose, all wineries (except 5 trading companies in 2022 and 6 in 2023 without grape production area) are sorted in ascending order according to their vineyard area and divided into four categories. These categories are defined to accurately reflect the entire business structure of the Austrian wine industry. The majority of wineries, 86%, manage total vineyards areas between 2 and 6 hectares, which highlights the prevalence of small-scale wineries. 8% of wineries operate vineyard acreages ranging from 10 to 20 hectares, while 5% manage between 20 and 100 hectares. Only 1% of the wineries operate on a larger scale with vineyards over 200 hectares. [10]

**Table 10.** Wineries with an area of ≤ 10 hectares (very small-sized).

| | 2022 | 2023 |
|---|---|---|
| number of grape suppliers | 89 | 118 |
| vineyard area | 410.24 | 490.51 |
| number of wine producers | 121 | 200 |
| vineyard area | 731.16 | 1,138.12 |

**Table 11.** Wineries with an area of 10 to 30 hectares (small-sized).

| | 2022 | 2023 |
|---|---|---|
| number of grape suppliers | 47 | 47 |
| vineyard area | 779.76 | 795.40 |
| number of wine producers | 157 | 172 |
| vineyard area | 2,622.25 | 2,847.29 |

**Table 12.** Wineries with an area of 30 to 80 hectares (medium-sized).

| | 2022 | 2023 |
|---|---|---|
| number of grape suppliers | 11 | 12 |
| vineyard area | 380.62 | 469.34 |
| number of wine producers | 61 | 59 |
| vineyard area | 2,767.24 | 2,732.07 |

**Table 13.** Wineries with an area of ≥ 80 hectares (large-sized).

| | 2022 | 2023 |
|---|---|---|
| number of grape suppliers | 1 | 0 |
| vineyard area | 82.53 | 0 |
| number of wine producers | 16 | 16 |
| vineyard area | 3,331.53 | 3,286.61 |

Based on the previously described clustering of wineries according to their vineyard area, detailed analyses were performed to examine GHG emissions in different production areas. This clustering made it possible to identify differences in emissions between very small, small, medium-sized and large wineries and to work out possible economies of scale.

The following analysis shows the share of total emissions from **grape suppliers** between the different clusters.

– The share of emissions from *vineyard replanting* is consistent across the categories, ranging from 32% (2023: 31%) for very small-sized wineries to 34% (2023: 33%) of the total emissions for medium-sized (30-80 hectares) wineries.
– Similarly, grape production consistently accounts for 68% (2023: 69%) to 66% (2023: 67%) of total emissions, irrespective of the operation size.

This suggests that both vineyard replanting and grape production require similar resources across wineries, regardless of their scale.

The following analysis shows how the size of a **wine producer** influences the relative shares of the individual emission sources and which areas make the greatest contribution to environmental pollution.

– With Very small wineries (≤10 ha) 8% (2023: 9%) of emissions can be attributed to *vineyard replanting*, while larger operations (≥80 ha) have a smaller share at 4% (2023: 4%). This suggests economies of scale in vineyard setup.
– Emissions in the area of *grape production* also decline as operations grow, from 20% (2023: 22%) for the smallest operations to 10% (2023: 11%) for the largest.
– While with very small-sized wineries show 27% (2023: 23%) of emissions come from *wine production*, this percentage decreases to 12% (2023: 12%) for larger wineries, likely reflecting operational complexity and production efficiency.
– The area of *small units* consistently accounts for the largest share of emissions, growing from 34% (2023: 34%) with very small wineries to 56% (2023: 55%) with large wineries. The substantial contribution from small units, particularly in large wineries, points to the high environmental cost associated with packaging in smaller units.

This additionally highlights that smaller wineries are more likely to use refilled containers, contributing to more sustainable practices, while larger wineries and trade companies primarily rely on new glass bottles. Wineries with ≤ 10 hectares have the highest percentage of refilled containers, at 56.89%. Large-scale wineries with ≥ 80 hectares have a very low refilling rate of only 0.40%.

– The increase in *packaging* emissions, from 11% (2023: 12%) with very small wineries to 18% (2023: 18%) in large wineries, can be attributed to the different packaging practices across winery sizes. Very small wineries (≤ 10 hectares) package 17% of their products in crates and sell 20% without packaging (loose). In contrast, larger wineries (≥ 80 hectares) package only 4% in crates and sell 5% without packaging. Wineries larger than 10 hectares predominantly use cardboard cases for packaging, with an increasing preference for cardboards with at least 50% recycled content.

Overall, the data reveals that while larger wineries benefit from reduced emissions in some areas due to scale, packaging, especially small units, as it is common practice with these wineries, remains a significant source of emissions regardless of winery size. This points to potential areas for improving environmental sustainability, particularly in packaging.

It is important to note, however, that the scale effect has a significant impact on wine producers, but not on grape suppliers.

## 4. Conclusion

The evaluation of the carbon footprint in Austrian viticulture for both grape suppliers and wine producers enables a clear distinction in emission sources and their proportional contributions. Vineyard replanting and grape production remain consistent contributors to emissions across all regions and estate sizes. This consistency underscores the fact that both small and large wineries face similar resource needs during these stages. However, economies of scale become more evident in the later stages of production.

Smaller wineries, those managing less than 10 hectares tend to rely more on sustainable practices, such as refilling containers, which helps mitigate their emissions. In contrast, larger wineries and trading companies predominantly use new glass bottles, contributing significantly to their overall carbon footprint. This disparity is particularly evident in packaging, where small units and packaging practices account for an increasing proportion of emissions as the size of the winery grows.

It is observed that wine producers invest more heavily in vineyard management practices than grape suppliers, especially to maintain high-quality standards. This results in higher $CO_2$-emissions per hectare among wine producers, as they perform additional soil management and plant protection measures to safeguard the quality of their grapes.

The key finding of this study is that while larger operations benefit from reduced emissions due to scale in some areas, packaging remains a critical point of concern for all wineries. Improvements in sustainable packaging practices e.g. refilling of glass bottles, especially among larger producers, would be a valuable step towards reducing the carbon footprint of the Austrian wine industry.

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## 6. Appendix

**Appendix 1.** Carbon footprint impact for wine producers and grape suppliers.

| category | *wine producers* | | | | *grape suppliers* | | | | measures |
|---|---|---|---|---|---|---|---|---|---|
| | *in % of the balance sheet* | | *in % of the category* | | *in % of the balance sheet* | | *in % of the category* | | |
| | 2022 | 2023 | 2022 | 2023 | 2022 | 2023 | 2022 | 2023 | |
| vineyard replanting | 5 | 5 | 100 | 100 | 33 | 33 | 100 | 100 | vineyard replanting |
| use of fuel / year | 0 | 0 | 0,3 | 0,3 | 0 | 0 | 0,7 | 0,4 | use of biodiesel per year |
| | 9 | 10 | 75,2 | 75,3 | 49 | 49 | 73,8 | 73,8 | use of conventional fuel (diesel, gasoline) |
| plant protection products - fungicides | 0 | 0 | 2,1 | 1,6 | 4 | 4 | 6,7 | 5,9 | fungicide - up to 6 treatments |
| | 1 | 1 | 8,1 | 8,9 | 3 | 4 | 5,1 | 6,0 | fungicide - 7 to 11 treatments |
| | 0 | 0 | 0,4 | 0,5 | 0 | 0 | 0,0 | 0,0 | fungicide - 12 treatments and more |
| plant protection products - fungicides (organic) | 0 | 0 | 0,1 | 0,2 | 0 | 0 | 0,4 | 0,4 | fungicide - up to 8 treatments |
| | 0 | 0 | 1,8 | 1,9 | 2 | 2 | 2,7 | 2,7 | fungicide - 9 to 14 treatments |
| | 0 | 0 | 0,2 | 0,3 | 0 | 0 | 0,0 | 0,1 | fungicide - 15 treatments and above |
| plant protection products - insecticide | 0 | 0 | 0,3 | 0,2 | 0 | 0 | 0,5 | 0,3 | insecticide - 1 to 3 treatments |
| | 0 | 0 | 0,0 | 0,0 | 0 | 0 | 0,1 | 0,1 | insecticide - more than 3 treatments |
| adequate planting/green manuring | 0 | 0 | 0,2 | 0,2 | 0 | 0 | 0,5 | 0,4 | autumn/winter planting 4 to 6 months |
| | 0 | 0 | 1,0 | 0,9 | 2 | 1 | 2,4 | 2,1 | autumn/winter planting > 6 months |
| | 0 | 0 | 0,2 | 0,3 | 0 | 0 | 0,1 | 0,1 | spring/summer planting > 3 months |
| | 0 | 0 | 1,5 | 1,7 | 1 | 1 | 0,9 | 1,1 | biennial and perennial greening (permanent greening) |
| use of fertilizer / ha | 0 | 0 | 0,5 | 0,5 | 0 | 0 | 0,6 | 0,6 | stable manure > 10,000 kg* |
| | 0 | 0 | 2,2 | 2,3 | 0 | 1 | 0,7 | 1,6 | compost > 4,000 kg dry matter** |
| | 0 | 0 | 0,2 | 0,1 | 0 | 0 | 0,2 | 0,2 | straw, bark mulch > 5,000 kg |
| | 0 | 0 | 2,0 | 2,0 | 2 | 1 | 2,7 | 2,2 | organic commercial fertilizers up to 1,000 kg |
| | 0 | 0 | 0,7 | 0,7 | 0 | 0 | 0,1 | 0,3 | organic commercial fertilizers > 1,000 kg* |
| | 0 | 0 | 3,1 | 2,4 | 1 | 1 | 1,7 | 1,9 | use of mineral nitrogen fertilizers in kg of pure nitrogen in the last 3 years |
| energy supply | 0 | 0 | 3,4 | 3,2 | | | | | use of renewable energies (PV, solar thermal energy, ambient heat, wind and hydropower) |
| | 0 | 0 | 0,9 | 0,9 | | | | | biomass (from the region) |
| | 0 | 0 | 0,7 | 0,7 | | | | | green electricity from the grid |
| | 0 | 0 | 2,0 | 1,1 | | | | | oil, diesel (wine production only) |
| | 2 | 2 | 13,8 | 13,9 | | | | | gas |
| | 1 | 1 | 6,6 | 6,6 | | | | | conventional electricity from the grid |
| | 0 | 0 | 0,1 | 0,3 | | | | | district heating with renewable energy sources and biomass |
| | 0 | 0 | 2,2 | 1,3 | | | | | district heating with conventional energy sources |
| mash tempering (white/rosé wine) | 2 | 2 | 12,2 | 16,2 | | | | | addition of carbonic acid snow |
| enrichment | 3 | 3 | 25,7 | 23,7 | | | | | addition of sucrose |
| | 0 | 0 | 0,0 | 0,1 | | | | | addition of Austrian grape must concentrate |
| | 0 | 0 | 2,2 | 1,3 | | | | | addition of rectified concentrated grape must |
| treatment measures | 1 | 1 | 6,5 | 6,5 | | | | | tartaric stabilization with metatartaric acid, gum arabic, carboxymethyl cellulose or mannoproteins |
| | 2 | 2 | 14,8 | 15,1 | | | | | mark-up for treatment measures |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| cleaning | 0 | 0 | 3,4 | 3,5 | | | | | mark-up for cellar cleaning |
| composting | 1 | 1 | 5,5 | 5,7 | | | | | composting mark up |
| small units | 51 | 51 | 97,4 | 97,5 | | | | | new glass in kg glass weight |
| | 0 | 0 | 0,0 | 0,0 | | | | | Tetra Pak/ soft packs |
| | 1 | 1 | 2,6 | 2,4 | | | | | PET/plastic hard packaging |
| | 0 | 0 | 0,0 | 0,1 | | | | | KEG (steel container) |
| closures | 0 | 0 | 0,3 | 0,3 | | | | | natural cork |
| | 0 | 0 | 0,4 | 0,3 | | | | | plastic closures |
| | 0 | 0 | 0,6 | 0,5 | | | | | glass closures |
| | 9 | 9 | 55,9 | 56,5 | | | | | screw caps |
| | 0 | 0 | 0,2 | 0,2 | | | | | crown caps |
| packaging | 0 | 0 | 0,0 | 0,1 | | | | | crates |
| | 2 | 2 | 12,0 | 11,1 | | | | | cardboard packaging < 50% recycled content |
| | 5 | 5 | 27,5 | 27,7 | | | | | cardboard packaging > 50% recycled content |
| labels | 1 | 1 | 3,2 | 3,3 | | | | | mark-up for labels |

* but in any case not more than 170 kg N per ha and year in accordance with the Nitrates Directive.

** but in any case no more than 8,000 kg dry matter per ha and year on a five-year average in accordance with the Compost Ordinance.