

Calculation of the CO₂ footprint using the example of Austrian wine

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A decarbonized society can only become reality if all potential greenhouse gas is leveraged. In order to achieve this, it is necessary to scrutinize all processes, to assess whether a high level of energy and material efficiency has been achieved and whether renewable energy sources are used to the maximum extent. In this investigation, we were investigating the corporate carbon footprint of a winery in Austria. All data, energy and material inputs were taken within the framework of a scenario analysis for one hectare of vineyard with a yield of a 5-year average of 5,380 litres. The energy and material input in a winery in Austria under the system limit considered in these calculations results in a GHG emission of about 1.04 kg per litre of bottled wine or 0.78 kg per 0.75-l bottle. On the other hand one kg of grapes would therefore cause 0.24 kg of CO₂e. The GHG emissions for the production of a wine bottle in Austria causes 0.328 kg CO₂ equivalent emissions. The GHG emissions for washing (0.011 kg CO₂ equivalent emissions per bottle), on the other hand, amount to only 3.4 % measured against a new bottle in Austria. The bag-in-box system can only be used once. This system leads to 59 % higher GHG emissions per litre compared to reusable bottles on the basis of 12 filling cycles (system sustainability – lightweight bottles). At a refill rate of 50 % in a winery, GHG emissions are reduced to 4,367 kg per ha (-32 % compared to normal and new glass in the winery). The calculations show that refilling the wine bottle has the highest savings potential. Measures to achieve this multiple use should be implemented as soon as possible in the wine industry. A replacement of synthetic fertilizers by green or farm manure and a substitution of fossil diesel with biodiesel would also result in important GHG reductions.

Key words: GHG emission, carbon footprint, lightweight bottles, reusable bottles, refilling wine bottles

Kalkulation des CO₂-Fußabdrucks am Beispiel der österreichischen Weinproduktion. Dieses Projekt befasst sich mit dem Corporate Carbon Footprint eines Weinbaubetriebs in Österreich. Sämtliche Angaben, Energie- und Materialeinsätze werden im Rahmen einer Szenarienbetrachtung für einen Hektar Weinbaufläche und einem 5-jährigen Durchschnittsertrag von 5.380 Liter angenommen. Der Energie- und Materialeinsatz in einem Weinbaubetrieb in Österreich unter der in diesen Berechnungen betrachteten Systemgrenze führt zu einer THG-Emission von rund 1,04 kg pro Liter abgefülltem Wein oder 0,78 kg pro 0,75-l Flasche. Davon entfallen 0,24 kg CO₂e auf ein kg Weintrauben. Rund 48 % der gesamten THG-Emissionen stammen von der Produktion der Weinflasche. Die THG-Emissionen für die Herstellung einer Weinflasche in Österreich verursachen 0,328 kg CO₂-Äquivalent-Emissionen. Die THG-Emissionen für das Waschen (0,011 kg CO₂-Äquivalent-Emissionen pro Flasche) betragen hingegen nur 3,4 % gemessen an einer neuen Flasche in Österreich. Das Bag-in-Box-System führt zu 59 % höheren THG-Emissionen pro Liter im Vergleich zu Mehrwegflaschen mit einer 12-maligen Wiederbefüllungsrate (Verwendung von Leichtglasflaschen). Werden in einem Betrieb 50 % der Flaschen wiederbefüllt, sinken die THG-Emissionen auf 4,367 kg pro ha (-32 % im Vergleich zur Verwendung von Einwegneuglas). Die Berechnungen zeigen, dass durch die Wiederbefüllung der Weinflasche das höchste Einsparungspotential gegeben ist. Maßnahmen, diese Mehrfachverwendung zu erreichen, sollten so rasch wie möglich in der Weinwirtschaft umgesetzt werden. Der Ersatz von mineralischen Düngemitteln durch organische Dünger oder Wirtschaftsdünger und die Substitution von fossilem Diesel durch Biodiesel würden ebenfalls zu erheblichen Treibhausgasreduktionen führen.

Schlagwörter: Treibhausgasemissionen, Kohlenstoff-Fußabdruck, Leichtglasflasche, Mehrwegflasche, Wiederbefüllung Weinflaschen

Introduction

The European Green Deal (EGD) has been proposed as a mission for Europe to become the world's first carbon neutral continent by 2050, targeting cutting greenhouse gas (GHG) emissions by at least 55% by 2030 (compared to 1990) (Wolf et al., 2021). Comparably, China also intends to reduce the CO₂ emissions from 2030 onwards and to achieve carbon neutrality by 2060 (UN 2020). A European climate strategy seeking carbon neutrality can only be successful if it shifts the economy to a new development path that generates broad social and political support early on (Wolf et al., 2021). The systematic recording of all greenhouse gas emissions caused directly and indirectly by a company's activities is named greenhouse gas balance (GHG balance) or carbon footprint (CFP). GHG balances can differ in terms of the scope of consideration (the system boundaries) or the reference, such as the consideration of an entire company (corporate carbon footprint) or an individual product only (product carbon footprint). A GHG balance provides information on the environmental performance of a company or product by specifying the climate-relevant environmental impacts of the area under consideration, in CO₂ equivalent emissions. These key figures can be used to compare different alternative courses of action and support strategic decisions. The preparation of a GHG balance often also reveals potential savings in material and energy resources (ISO 14067, 2018). GHG emissions are calculated with the help of GHG emission factors. They determine which emissions result from the use of the respective energy carrier and are expressed in CO₂-equivalent emissions (CO₂e). CO₂ equivalent is a unit for greenhouse gases that shows the global warming potential (GWP). In this assessment, the six main greenhouse gases are converted to the value of CO₂ using a weighting factor. With the weighting of the climate gases, the GWP refers to a time frame of 100 years. This means that, during this time interval, one kilogram of methane, for example, has 25 times the harmful effect of the same amount of carbon dioxide (IPCC, 2013). CO₂ equivalents are given in units of weight per reference value e.g. g CO₂e/kWh electricity, g CO₂e/kWh natural gas, g CO₂e/kWh gasoline, g CO₂e/km mileage or kg

CO₂e/kg refrigerant. In accordance with the resolution OIV-CST 503AB-2015 the gases or group of gases the emission and removal of which will be considered for the assessment are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), sulphur hexafluoride (SF₆), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). Emission factors are used to calculate and aggregate direct and indirect emissions. Direct emissions are those occurring directly at the point of energy conversion (e.g. in the boiler). Indirect emissions (or upstream) are emissions that occur additionally in upstream processes during energy and material production (e.g. petroleum extraction and processing into fuel oil). The sum of direct and indirect emissions forms the total emissions. The first edition of the GHG Protocol Corporate Accounting and Reporting Standard (WRI – WBCSD, 2011; WRI – WBCSD, 2014 and WRI – WBCSD, 2015) enjoyed broad adoption and acceptance around the globe by businesses, NGOs, and governments. Many industry, NGO and government GHG programs used the standard as a basis for their accounting and reporting systems. According to the GHG Protocol, emissions are classified and presented according to the so-called scopes: I) Scope 1 comprises the direct emissions caused by a company itself. II) Scope 2 includes the emissions from the generation of purchased electricity, steam, heat and cooling consumed by the organization. III) Scope 3 includes all other greenhouse gas emissions that result from the operations of the company, e.g. a winery. These emissions are, for example related to the provision of fuel and operating materials and material inputs. As already stated, the scope of consideration, namely the choice of the system boundary has a decisive influence on the carbon footprint results; the system boundary marks the boundary between the system under consideration and the system environment. The selection of included or excluded areas depends on the type of question, the data (keyword: availability and quality) and the materiality of the effect. In principle, the system boundary should represent all relevant GHG emissions from the process chain. By representing the system boundary, it is possible to calculate a resilient carbon footprint (WRI – WBCSD, 2004 and WRI – WBCSD, 2011) The determination of the carbon footprint (CFP) of products is standardised in ISO standard 14067 (2018), which stipulates that the

entire life cycle of the product, from the production of raw materials to the finished product is calculated. The carbon footprint can therefore be used as a measure for the quantity of greenhouse gases linked to the generation of a given product (ISO 14067, 2018). In many regions, agricultural production is affected by extreme variations and rising temperatures and increasing intensity of extreme weather events (FAO, 2022). On the other hand, agriculture was responsible for 13-21 % of global anthropogenic emissions of GHG in the years 2010-2019 (IPCC, 2022). The GHG balance of the vinivicultural sector is also topic of methodical recommendations of OIV (OIV, 2017). As with other production sectors, wine production and consumption contribute to GHG emissions. A recent study in Switzerland, based on ISO standard 14067, has determined that wine consumption in Switzerland is responsible for 2 % of the ecological footprint (calculated using the ecological scarcity method) (Jungbluth et al. 2012) or 0.5 % of greenhouse gas emissions (calculated using the "climate footprint") (Podzorski, 2019). Benedetto's study examined the production of a 0.75 l bottle of Vermentino di Sardegna, a typical white wine produced in Sardinia. The Life Cycle Assessment (LCA) took into account all production steps from planting the grapevines to bottling and packaging the wine (product carbon footprint). Grape production is responsible for emissions of 0.708 kg of CO₂ equivalents, which is 43.11 % of the total global warming potential (Benedetto, 2013). Gazulla et al. (2010) prepared a life cycle assessment for the production of Crianza in the region of La Rioja, Spain. The results show that the production of a 0.75 l bottle of Crianza emits a total of 0.503 kg of CO₂ equivalents in grape production, which is about half of the total. The WEINKLIM project considered the question of how greenhouse gas emissions can be reduced in the Austrian wine industry. "The carbon footprint calculations for grape production in the vineyard resulted in 0.34±0.13 kg CO₂e per kg grapes or 0.47±0.17 kg CO₂e per l wine (excluding soil emissions). The largest contribution was caused by diesel consumption, followed by mineral fertilisers and plant protection products. ... The further process steps in wine production caused 1.27±0.84 kg CO₂e per l of wine, of which the packaging in the form of the traditional glass bottle caused the largest share. For the transport to the customer (mostly self-collection) another

0.24±0.29 kg CO₂e per litre were added. In total, a carbon footprint of about 1.7 and 1.9 kg CO₂e per litre of wine (without and with transport, respectively) was calculated for Traisentaler Wein for the entire product life cycle from the vineyard to the customer" (Soja et al., 2010). In consequence, in the wine industry, efforts are made to determine the carbon footprint of wine production aiming to identify the main polluters in the production chain and to identify savings potential. For example, glass bottles cause around 47 % and fertilisers 12 % of GHG emissions of the total production chain. On the other hand, the use of lightweight glass bottles instead of standard glass bottles can save 39 %, biodiesel instead of fossil diesel 43 %, conversion to green electricity (eco-label 46) 93 % or natural cork instead of aluminium capsules 52 % of GHG emissions. (Palmes et al. 2013; Poelz et al., 2020). Taking previous studies on the carbon footprint of fruits and vegetable crops (Emberger-Klein et al., 2015) as well as in administration (EIP, 2021) as examples, the carbon footprint of products such as wine should be calculated in the future and used as an internal tool and for business-to-business (B2B) communication in the value chain. Furthermore, the industry should increasingly educate consumers in respect to the climate impact of their products or address the climate impact of their products by, for example, emphasizing specific benefits of food and clarifying the benefits of certain production methods. Consumers should also be provided with tools allowing them to make more informed purchasing decisions regarding climate impacts. For the certification tool "Sustainable Austria" (www.sustainableaustria.com) all relevant data for greenhouse gas balancing in Austrian wine production have been collected, evaluated and implemented in the sustainability certification in the period 2020 to 2022 so that an GHG balance is automatically calculated (Poelz et al., 2020). In this paper, the individual and automatic calculation of the greenhouse balance in the certification tool "Sustainable Austria" for Austrian wineries is outlined and discussed in detail, including preliminary work already published (Poelz et al., 2020). The focus of this paper is the question of the footprint per hectare of vineyard, per litre of bulk wine and per 0.75l bottle. The influence of individual activities in the vineyard and cellar on greenhouse gases is presented in a differentiated manner. Furthermore, the main polluters are determined

and solutions are evaluated. Particular attention has been paid to packaging, especially glass bottles, and attempts are made to find solutions for reducing greenhouse gas emissions. Different glass bottle weights as well as alternative packaging (e.g. bag-in-box) are evaluated and discussed in comparison. A central question is what influence a reusable bottle has on GHG through refilling. The use of diesel and fertiliser are also examined and evaluated to see if savings can be achieved with alternative strategies.

Material and methods

Life Cycle Assessment

The current standards for voluntary reporting of GHG emissions (GHG Protocol, ISO 14064-1) leave a great deal of freedom in the selection of calculation methods and data sources. Therefore, system boundaries must be clearly defined and documented for each study. According to ISO 14067 standards, the life cycle stages to be investigated in the balance are defined by the following system boundaries: i) Cradle-to-Grave: Includes emissions and removals that occur throughout the life of the product. ii) Cradle-to-Gate: Includes emissions and distances to the point where the product leaves the organization. In this work, the GHG emissions were analysed within the framework of "cradle-to-gate" of important production steps over the entire production chain of the product (0.75l bottle).

Global Emissions Model of Integrated Systems (GEMIS)

GEMIS is a freely available computer model for life cycle and material flow analyses in analyses for ecological damage. It was developed by Öko-Institut e.V. (Institute for Applied Ecology, Freiburg, Germany) and was created with funding from the Hessian Ministry of Environment and Economics in its first version in 1989. Since then, it has been continuously updated and expanded with funding from, among others, the German Federal Ministry for the Environment, the German Federal Ministry of Research, as well as the German Federal Environmental Agency, the GIZ, the EEA, and EU projects. In April 2012, GEMIS was transferred to the International Institute for Sustainability Analysis and Strategies

(IINAS), which will take over further development and data maintenance [GEMIS, 2021].

Based on existing research work, the Austrian Umweltbundesamt GmbH has further developed GEMIS with the aim of generating greenhouse gas and air pollutant balances for Austria with country-specific adaptation for energy and material processes. The adapted GEMIS tool takes into account all essential processes, starting from primary energy and raw material extraction up to useful energy and material supply, e.g. also auxiliary energy and material input for the production of energy plants and transport systems. It thus offers the possibility of considering not only direct emissions but also upstream process emissions, the so-called indirect emissions (GEMIS, 2021). The emission factors used for greenhouse gas balances in this adapted model are regularly compared to the data material from the Austrian Air Pollutant Inventory (OLI) and reflect the country-specific reality. Austria is obliged to compile an annual greenhouse gas inventory of all economic sectors (National Inventory Report – NIR, 2021). All calculations illustrated in the current study have been performed using this model.

Data basis and system limit of the current LCA study

The system boundary for the calculation of greenhouse gas emissions from a vineyard in Austria was set to the functional unit of one hectare of vineyard area in Austria and a wine yield of 6750 litres after fermentation on average. Vineyard area and the harvest volume are the basis for the energy and material inputs used. All energy and material inputs refer to this functional unit and one business year. The treatments between fermentation and bottling cause a loss of 7 %, which is taken into account in the calculations. This loss is generally assumed by Austrian tax authorities, and thus this quantity was adopted unreflectively from a technical point of view. The system boundary does not include business travel (air travel, rail travel), wine logistics (neither the company's own nor third-party fleet or delivery companies (e.g. DPD), refrigerant losses from the refrigeration machines, employee travel, and infrastructure construction materials (wine cellars, buildings, warehouses, wine tanks, wine presses).

Model winery and vineyard data assumed in the assessment

The current study is based on key performance indicators (KPI), namely relevant key figures allowing to define targets and plan suitable measures. Here, the KPI of a winery in Austria is defined as the total of GHG emissions in relation to the yield per year.

As illustrated above, an average grape yield with 9,000 kg and wine yield of 6750 litres minus 7 % treatment losses per ha of vineyard are taken as basis for the current calculations. Based on empirical values and, where available, data collections, the energy and material inputs for one ha of an average vineyard were compiled as illustrated in Table 1 and illustrated in detail below. These figures served as basis for the calculation of the KPI GHG emissions.

Table 1: Data basis for the calculation of greenhouse gas emissions from a vineyard in Austria for 1 hectare of vineyard area.

Area	Amount	Unit
Vineyard-infrastructure	4,349	kg steel (poles, stakes und wire)
Planting	3,570	Piece of vines
Tractor-energy input	1,650	kWh diesel (app. 160 litres)
Plant protection	11	kg plant protection products conventional
Fertilization	155	kg mineral fertilizer (40 kg nitrogen, 70 potassium, 20 kg phosphorus, 25 kg magnesium)
Enrichment	175	kg beet sugar
Fining products	19,5	kg (must and wine treatment agents)
Wine storage - Energy	1,600	kWh conventional electricity
Bottling - Energy	600	kWh conventional electricity
Winery - Energy	200	kWh conventional electricity
Bottle	8,370	pieces „Bordeaux 480 g“
Closures	25.1	kg aluminum capsules
Labelling	15.7	kg paper
Packaging	488.25	kg cardboard cases

The infrastructure of an average Austrian vineyards includes 3570 stakes (0.1 kg/stick), 715 poles (5 kg/pole), and 6000 linear meters of wire (25 kg per 1000 m). The construction of one vineyard is related to the assumed vineyard life of 30 years. For the management and harvest of 1 hectare of vineyards, 160 litres of diesel per year are required (source: data analysis in poelz et al, 2020; Rosner et al., 2015). Plant protection is taken into account with 11 kg of conventional/systemic plant protection products. In the study at hand, seven applications with 1.5 kg of product per treatment were assumed. The use of nitrogen through mineral fertilizers entails two different greenhouse gas effects. On the one hand, the Haber-Bosch process allows a synthetic production of nitrogen fertilizers. However, this process requires a high energy input, which results in corresponding greenhouse gas emissions. On the other hand, nitrous oxide is emitted during nitrogen applications. This gas has up to 300 times higher

greenhouse gas potential than CO₂. Nitrous oxide emissions are included in the calculations based on the amount of nitrogen added, regardless of the type of fertilizer (mineral fertilizer, farm manure, compost, or green manure). In a guideline issued by the Austrian Ministry for Agriculture, Forestry, Regions and Water Management, fertilizer input per hectare amounts to 40 kg of pure nitrogen, 70 kg of potassium, 20 kg of phosphorus, and 25 kg of magnesium per year (BMLFUW, 2020). These quantities have been included in the current assessment. In the winery, 175 kg of sugar are used to enrich the 6,750 litres by 2 degrees “Klosterneuburger Mostwaage” (KMW). Since the quantity refers to the fermented wine and not to the must, the increase in volume due to the addition of sucrose is not taken into account. For all must and wine treatments (protein, tannin and clarification), 19.5 kg of medium is factored in to the actual calculation. The by far largest part of this quantity is made up by bentonite. The

energy input in the form of electricity in the wine cellar, during wine storage through to bottling, is around 2,400 kWh for 6,750 litres minus 7 % treatment loss in the winery. The electricity use of 2,400 kWh in the cellar up to bottling includes the following operations: grape pressing, must and wine pumping, cleaning work with steam cleaning equipment (e.g. Kärcher high-pressure cleaners); stirring of wine (addition of fining agent); sterilisation of the bottling plant. All energy quantities were defined as electricity. 2,400 kWh electricity cause 641 kg CO₂ equivalent emissions. This corresponds to an average electricity park in Austria. For the bottling of the wine produced in one ha of vineyard, 8,370 0.75l Bordeaux-style/claret bottles with a net weight of 480 g are assumed in the calculations. Packaging (488.25 kg for the cardboard wine cases at a weight of 0.350 g/6 cases), 15.7 kg labels and 25.1 kg aluminum

capsule closures (4 kg per 1000 litres) are included in the system limit.

Impact of measures to improve the GHG emissions of the model winery

Types of glass bottles, alternative small packaging and reuse of packaging

Our previous study revealed that the glass bottle accounts for 47 % of the CO₂ footprint generated during production (Poelz et al., 2020). In consequence, the current study aimed to investigate the impact of different glass bottles. The use of lightweight glass bottles as well as the use of glass bottles exclusively produced by fossil fuel energy were analysed. In addition, we investigated the potential of alternative packages for emission reduction. The packages outlined in Table 2 were included in the study.

Table 2: Types of small packages included in the study. Numbers of possible refills for each type are stated.

small packaging	technical description	number of possible refills
Bag-in-box	Material: PET outer film for oxygen-sensitive products such as wine, fruit concentrates and fruit preparations. Tare weight: 0.056 kg (without carton); Capacity: 3 l, disposable	1
KEG-steel tanks	Euro KEG 20 l, calibrated, KEG tanks for storage of beer, wine and juice. Dead weight: 4.5 kg; capacity: 20 l; returnable	100
Sustainability - re- turnable bottle (Austria)	Glass bottle production in Austria: share of cullet at least 75 % and energy mix average Austria; share of renewable energy in energy mix average; tare weight: 0.480 kg/bottle (average weight between Bordeaux and Rhine wine bottle); capacity: 0.75 l; reusable according to eco-label 26 "Reusable containers and reusable cup systems" with a refill rate of 12	12
Exclusive returnable bottle (Austria)	Glass bottle production Austria (share of cullet at least 75 %; energy mix average in Austria; share of renewable energy sources in energy mix average; tare weight: 0.600 kg/bottle; capacity: 0.75 l; reusable according to eco-label 26 "Reusable containers and reusable cup systems" with a refill rate of 12	12
Disposable bottle (inter- national) – one way	Glass bottle production international (no cullet; share 100 % fossil fuels in the energy mix; net weight: 0.600 kg/bottle; capacity: 0.75 l; disposable	1
PET bottle (primary materials)	PET bottle for the production of which primary materials were used and a bottle weight of 60g/0.75l bottle is assumed.	1
PET bottle (secondary materials)	PET bottle for the production of which secondary materials were used and a bottle weight of 50g/0.75l bottle is assumed.	1

GHG emissions caused by bottle cleaning

Refilling of small containers requires a precise cleaning procedure before the packaging can be reused. In order to include the actual effect of bottle cleaning into our assessments we requested data for large-scale and modern machinery from the company Krones in Neutraubling, Germany (Krones, 2023), selling bottling and packaging equipment. Data per bottle during bottle washing in small-scale and standard operations were compiled based on empirical values. Case studies from Krones, Germany, were used to calculate the energy and material consumption on the one hand for bottle washing as part of a rinsing centre (appendix 1) and comparatively for the cleaning and filling of

returnable glass bottles (appendix 2). As a basis for the calculation a refill rate of 12 times was assumed. It will also be investigated what GHG reduction occurs in a winery if the share of refilled bottles is 50 %.

Use of biofuel

The use of biofuels in Austria is controlled and must lead to a reduction of GHG emissions. The 2012 Fuel Ordinance (KVO) transposes the Directive on the Promotion of Renewable Energy Sources (28/2009/EC) into national law. The KVO provides for the use of biofuels with shares of 6.3 % for diesel fuel and 3.4 % for petrol fuel, respectively. (KVO, 2012). The use of biofuels must lead to a greenhouse gas reduction of 6 %

in fuel use in Austria along the entire value chain. The Federal Environment Agency has set up the monitoring system eINa (electronic sustainability certificate), with which the mass balance can be complied with and checked. In Austria, biodiesel from unknown sources is not allowed to be traded. Due to these two facts, certified biodiesel is used in the GHG calculations.

Fertilization

Viticulture without fertilization is not successful in the long run. In consequence, renouncing fertilization was not considered as an alternative scenario in this study. However, synthetic fertilizers can be replaced by farm manure and the use of compost replaces the application of mineral fertiliser. Nitrogen fertiliser production in particular is very energy-consuming and thus emissions-intensive. The effect of this strategy - using compost instead of commercial fertiliser - was analysed in the study.

Results and discussion

GHG- emissions of an average Austrian winery per ha vineyard, litre of wine and 0.75-l bottle with a detailed account of the cause

Based on the assumptions and data stated above, the GHG emissions of a winegrowing operation for 1 hectare in Austria amount to 6,591 kg CO₂ equivalent. The largest share of the GHG emissions is related to Scope 3, namely 82.1 %, 9.8 % are related to Scope 1 and 8.1% to Scope 2 (Table 3). Assuming a yield per hectare of 6,277 litres (6,750 litres minus 7 % loss), the KPI of a winery is 0.91 kg CO₂ equivalent emissions per litre of bottled wine or 0.68 per 0.75l bottle. Grape production accounts for 1,733 kg CO₂ equivalent per ha. Assuming a yield of 9,000 kg per ha, 1 kg of grapes would cause 0.19 kg CO₂e.

Table 3: Greenhouse gas emissions in kg CO₂eq per scope, per area and in total for a model winery in

GHG-emissions	Scope 1	Scope 2	Scope 3	Sum total	Unit	% share
Vineyard establishment			417	417	kg	6.4
Diesel (tractor)	414		107	521	kg	8.0
Plant protection products			128	128	kg	2.0
Fertilization	213		454	667	kg	10.3
Enrichment			263	263	kg	4.0
Wine treatment products			30	30	kg	0.5
Electricity use (cellar to bottling)		515	126	641	kg	9.9
Bottle			3,119	3,119	kg	48.0
Closures+labels+cardboard cases			710	710	kg	10.9
Sum	627	515	5,354	6,496	kg	100
Share in %	9.7	7.9	82.4	100	%	

The biggest share of the emissions, namely 3,119 kg (48 %) are caused by the bottle packs. Fertilization (including the nitrous gas emissions) accounts for 667 kg, (10.3 %). Electrical energy use contributes 641 kg (9.9 %) and diesel use 521 kg (8.0 %) to the GHG emissions. Referring to a 30-year life cycle of a vineyard, annual material inputs for the establishment of a new vineyard amount to 417 kg (6.4 %). The closures including labels and cardboard boxes cause 710 kg (10.9 %). The enrichment with 263 kg (4.0 %), the plant protection products with 128 kg (2.0 %) and the wine treatment products with 30 kg (0.5 %) together make up 6.5 % of the GHG emissions. A

calculation of GHG emissions as outlined above allows, based on the presented key performance indicators (KPI), an unequivocal identification of areas with high impact on GHG balances. In consequence, suitable measures can be planned and implemented. As an example, the current study highlights the enormous contribution of glass bottles to the total GHG emissions. The material input for 8,370 bottles is massive and can be traced back to high emissions during production and transport of the bottles. Strategies to reduce this material use could greatly influence the GHG balance.

As already outlined, an average wine yield of 6,277 litres per ha of vineyard were taken as basis for the current calculations. The effective yield of a winery, however, massively depends on the vintage-specific conditions. The climatic conditions of a given vegetation period have a great impact on vine development, e.g. on flowering and bunch and berry size, in consequence, annual yields may vary greatly. Yield differences have a relevant impact on the GHG emissions per bottle or litre of wine, because input in many areas, such as vineyard management or harvest of the grapes occurs independently of harvest size. According to Statistics Austria, the 5-year average harvest in Lower Austria is 5380 litres per hectare (StatistikAustria, 2022). Compared to the assumptions for the model vineyard outlined above, the lower harvest can be filled in 7174 instead of 8,370 bottles and the required amount of sugar decreases from 175 kg to 140 kg. Based on the 5-year yield average GHG emissions amount to 5,771 kg per hectare and 1.04 kg of CO₂-equivalent emissions per litre of wine. One kg of grapes would therefore cause 0.24 kg of CO₂e.

Impact of different glass bottles weights, alternative packaging and refilling on GHG emissions

Different glass bottle weights

The use of lightweight glass (370 g) instead of normal glass (480 g) leads to a reduction in material input without changing the filling capacity. The lightweight glass bottle lowers the material input by around 23 % and thus the GHG emissions to the same extent. All in all, the use of lightweight glass instead of normal glass diminishes the total GHG emissions of the model winery to 5630 kg per hectare (-12 % compared to normal glass in the model winery described above). Compared to other countries the rate of glass recycling in Austria (75 %) is outstanding. Assuming the use only of primary glass and exclusively fossil energy sources for the production of wine bottles, the emission factor for glass production would increase by about 48 %. This is based on the fact that 3% energy and 7 % CO emissions are saved for every 10% of used glass in new bottle production (vetropack, 2023). Under the assumptions of fossil-produced wine bottles, GHG emissions would come to 8012 kg (+25 % compared to normal glass in the wine operation described above).

Alternative small packaging and reuse of packaging

The outcome of our model calculations, investigating the potential of alternative packaging for emission reduction, are outlined in Table 4.

Table 4: Impact of small packaging and possible refills on GHG emissions in kg per small container unit and GHG emissions in kg per litre of wine in accordance with table 2

Container type	GHG emissions in kg per small container unit	GHG emissions in kg per litre	GHG emissions in kg per litre in case of refilling
Bag-in-box	0.152	0.051	0.051
KEG steel container	11.02	0.551	0.006
Sustainability - returnable 0.370 kg/0.75 litre bottle (Austria)	0.287	0.383	0.032
Exclusive returnable 0.600 kg/0.75 litre bottle (Austria)	0.466	0.621	0.052
Disposable 0.600 kg/0.75 litre bottle (international) – one way	0.570	0.760	0.760
PET bottle (primary materials) kg/0.75 litre bottle	0.183	0.244	0.244
PET bottle (secondary materials) kg/0.75 litre bottle	0.11	0.147	0.147

The bag-in-box system can only be used once. This system leads to 59 % higher GHG emissions per litre compared to reusable bottles (system "Sustainability"). The higher material input for the "Exclusive" glass bottle (600 g, it requires 71 % more material than the "Sustainability" system (370 g)) is also reflected in the GHG emissions. The "Exclusive" system would therefore have to be used 7 times more often to achieve the same GHG emissions as the "Sustainability" system.

At a refill rate of 50 %, as shown in table 4 with a 370g/0.75l bottle and a refill rate of 12, GHG emissions are reduced to 4,367 kg per ha (-32 % compared to common 480g/0.75 l glass in the winery described above). The refilling of wine bottles represents the largest GHG savings effect in a winery. It can be unequivocally concluded that the refilling of small container systems is the essential step towards a wine industry with low greenhouse gas emissions.

GHG emissions caused by bottle cleaning

As outlined above, the reuse of glass bottles is of crucial importance in a development towards low GHG emissions in wine production. However, reuse results in GHG emission due to bottle cleaning, which needs to be considered in a total balance. Calculations based on the data by the company Krones are illustrated in Table 4 and attachments 1 and 2. The GHG emissions for washing amount to 0.011 kg CO₂ equivalent emissions per bottle (emissions data from company Krones; Krones, 2022). Small or standard scale bottle washing are a little less environmentally friendly, in this case a value of 0.028 kg per bottle was calculated (Table 5). In any case, GHG emissions for bottle washing are far lower than emissions for the production of new bottles. For example, the production of one light glass bottle (370 g, Vetropack) emits 0.296 kg CO₂ equivalents, compared to the production of one standard bottle (0.75 l, 480 g, Vetropack) 0.328 kg CO₂ equivalent. All in all, the data indicate that despite the necessity for washing, the reuse of glass bottles remains by far the most effective measure in respect to GHG savings.

Table 5: GHG emissions per bottle during bottle washing in large-scale and modern operations (Original table)

Wine bottle cleaning (reuse)	Steam energy (heat) in kWh/bottle (refillable)	Natural gas for steam energy (heat) in kWh/bottle	Electricity energy in kWh/bottle (refillable)	Energy consumption in kWh/bottle	GHG emissions in kg/bottle
Data KRONES	0.0217	0.024	0.0177	0.042	0.011
Details bottler Weinviertel	Litres of fuel oil/1100 bottles	kWh heating oil/1100 bottles	Energy consumption in kWh/bottle	GHG emissions kg/bottle	Total GHG emissions in kg/bottle
Thermal fuel oil	9.67	93.01	0.085	0.022	0.02832
Electricity input		25.00	0.023	0.006	

Impact of fertilization

The Austrian recommended "Good Agricultural Practice" recommends mineral fertilizer (40 kg nitrogen, 70 potassium, 20 kg phosphorus, 25 kg magnesium) per year for viticulture. The use of farm manure in combination with permanent green cover containing legumes instead of mineral fertilizer can reduce GHG emissions to 6,045 kg per hectare (-5.5 % compared to mineral fertilization in the vineyard described above). However, a complete renunciation of fertilization is not a sustainable strategy in viticulture. Well-supplied soils are essential for long-lasting, vital vineyards and the production of ripe, healthy grapes. Farm fertilizers can supply both nitrogen and the main nutrients to the soil. Likely, a (partial) replacement of synthetic fertilizers by green or farm manure could significantly contribute to a GHG reduction.

Impact of fuels

The complete substitution of fossil diesel (160-l/ha) with biodiesel can reduce GHG emissions to 6,154 kg (-3.8 % compared to fossil diesel in the winery described above). An important point of discussion is whether the production of biodiesel has caused any direct land use changes (DLUCs). If the feedstock comes from agricultural land,

indirect land use changes (ILUCs; Baral and Malins, 2016) must be taken into account. In this case, the cultivation leads to a shortfall in the harvest of other agricultural products that would otherwise have been cultivated on this land. This shortfall must now be compensated. This can be done either by ploughing up a new, previously uncultivated natural area for cultivation elsewhere. In this case, extensive biodiversity effects are clearly indirectly triggered. However, it is also possible that currently unused fallow land is used for this cultivation. Since fallow land in the agricultural landscape plays a crucial role in maintaining open land biodiversity, this variant is also clearly negative in terms of effects. The third possibility is that the lost area for biodiesel production is compensated for by a massive intensification of cultivation on existing land. Such intensification would be land-neutral, but it would require possibly the increased use of plant protection agents, which in turn would have negative effects. The problem of indirect land use change has been discussed extensively in the literature for some time (e.g. Kim and Dale, 2011; O'Hare et al., 2011). In addition to the sustainability effects, it must also be checked whether all machines are suitable for the use of biodiesel, which entails new investments for older types.

Conclusions

The energy and material input in a winery in Austria under the system limit considered in the current study amounts to 6,994 kg of GHG emissions per hectare. This corresponds to a GHG emission of about 1.03 kg per litre of wine. By far the largest share, namely more than 48 % of the total GHG emissions, are related to the wine glass bottle. The calculations outlined in the current study clearly illustrate that refilling the wine bottle offers the highest savings potential. This assumption is based on ideal conditions that include a return of empty containers to the winery (e.g. automatic redemption in case of new delivery). A national initiative, which is currently realised in the project "Mehrweg Bouteille" (refilling of the 0.75-l bottle) in Austria, is examining what actual GHG effects would be incurred if a collection system were introduced.

The introduction of crates instead of cardboard cases could have additional effects. On the other hand, central washing centres would also require increased energy input, as the washed glass bottle – in contrast to immediate reuse in the winery – must include an additional drying and packaging step. Mineral fertilizers on the scale assumed in this study account for around 10 % of the total greenhouse gas emissions. Sustainable GHG saving in this area must include a sufficiently good balance between required fertilizer applications and fertilizer origin. In the future, green manure, farm manure and compost could successfully contribute to the reduction of fertilization related GHG emissions.

Fossil fuel in tractors accounts for around 8 % of the total greenhouse gas emissions. The use of alternative fuels or alternative drive systems (keyword: electric drive) can reduce this share.

Detailed GHG calculations can be found in Appendix 3.

Appendix 1: Case study washing centre for returnable wine bottle 750 ml @ 10,000 bph; source: Krones, Germany

Machine	Electrical energy (kWh)	Low-pressure air (Nm ³ /h)	Process water (m ³ /h)	Steam (kWh)	CO ₂ (kg/h)	Cooling energy - refrigeration system (kWh)
Combined unloader and loader	5.0	15.0				
Sorting of foreign bottles	0.5	3.0				
Bottle washing machine	35.0	1.0	2.75	200.0		
Inspection module for self-adhesive labels	0.5					
Empty bottle inspector	1.0	10.0				
Container transport	13.0		0.55			
Packages transport	11.0					
Pallet transport	2.0					
Unpacker	2.5	5.0				
Packer	2.5	5.0				
Unscrewers	6.0	1.0				
Box washer (hot)	15.0	0.5	0.5	25.0		
Film winder	5.0	12.0				
Quantity/hour	99.0	52.5	3.8	225.0	0.0	0.0
Consumption per 1,000 bottles	9.9	5.3	0.4	22.5	0.0	0.0

Appendix 2: Case study washing and filling centre for returnable wine bottle 750 ml @ 6,000 bph; source: Krones, Germany

Machine	Electrical energy (kWh)	Low-pressure air (Nm ³ /h)	Process water (m ³ /h)	Steam (kWh)	CO ₂ (kg/h)	Cooling energy - refrigeration system (kWh)
Bottel slider	2.8	14.0				
Empty bottle inspector	0.8	8.3				
Feeding system for closures	0.8	0.3				
Control system for filler and capper (incl. VS blow-off)	0.5	50.0				
Control system for labels	0.5					
Container dryer	14.5					
Palletiser	3.0	15.0				
Disposable packer - case	4.5	18.0				
Labelling machine	3.6	20.0				
Rinser - 1 channel	5.0	3.0	0.8			
Filler with vacuum pump	10.0	40.0	0.3		16.0	5.0
Container transport	8.0		0.4			
Packages transport	5.0					
Pallet transport slider	2.5					
Pallet transport loader	2.5					
Capsule machine	5.0	25.0				
Injector	1.0					
Film winder	4.0	10.0				
Container labeller	1.0					
Container inspector	0.5					
Bottle washing machine	30.0	1.0	1.5	130.0		
Container sorter	0.5	3.0				
Quantity/hour	106.0	207.8	3.0	130.0	16.0	5.0
Consumption per 1,000 bottles	17.7	34.6	0.5	21.7	2.7	0.8

Appendix 3: GHG emission factors for selected energy sources and materials [source: GEMIS - Global Emissions Model of Integrated Systems 5.0]

Energy sources and materials	Scope 1	Scope 2	Scope 3	Unit
Electricity production in Austria 2020		214,6	52,4	g CO ₂ equivalent emissions per kWh
Diesel (combustion)	255		65,7	g CO ₂ equivalent emissions per kWh
Wine treatment agent PVPP			12,2	g CO ₂ equivalent emissions per kWh
Filtration material diatomaceous earth			0,03	g CO ₂ equivalent emissions per kWh
Dried yeast			2,6	g CO ₂ equivalent emissions per kWh
Gelatine (liquid)			1	g CO ₂ equivalent emissions per kWh
Activated charcoal			0,6	g CO ₂ equivalent emissions per kWh
Enzymes			6,77	g CO ₂ equivalent emissions per kWh
Bottles/refillable Austria			0,8	g CO ₂ equivalent emissions per kWh
Bottles/disposable international fossil			1,15	g CO ₂ equivalent emissions per kWh
Bag in Box			3,1	g CO ₂ equivalent emissions per kWh
KEG- Stainless steel barrels			2,45	g CO ₂ equivalent emissions per kWh
Screw cap (aluminium)			19,5	g CO ₂ equivalent emissions per kWh
Cork			1,4	g CO ₂ equivalent emissions per kWh
Labels			1,5	g CO ₂ equivalent emissions per kWh
Cardboard			0,80	g CO ₂ equivalent emissions per kWh
Crop protection products conventional			12,2	g CO ₂ equivalent emissions per kWh
Nitrous oxide emissions from soil nitrogen	5,32			g CO ₂ equivalent emissions per kWh
Nitrogen - mineral fertiliser production			7,8	g CO ₂ equivalent emissions per kWh
Potassium - mineral fertiliser production			1,30	g CO ₂ equivalent emissions per kWh
Phosphorus - mineral fertiliser production			1,0	g CO ₂ equivalent emissions per kWh
Magnesium - mineral Fertiliser Production			1,20	g CO ₂ equivalent emissions per kWh
Sucrose			1,5	g CO ₂ equivalent emissions per kWh
Steel poles			2,40	g CO ₂ equivalent emissions per kWh
Vine planting material			1,0	g CO ₂ equivalent emissions per kWh
Wire			2,40	g CO ₂ equivalent emissions per kWh
Concrete pole			2,8	g CO ₂ equivalent emissions per kWh
Plastic pole			3,22	g CO ₂ equivalent emissions per kWh
Wooden pole			0,2	g CO ₂ equivalent emissions per kWh
Wooden stakes			0,20	g CO ₂ equivalent emissions per kWh
Steel stakes			2,4	g CO ₂ equivalent emissions per kWh
Plastic stakes			3,22	g CO ₂ equivalent emissions per kWh

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