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Article

Reduction of carbon footprint by using recyclable bottles—A case study on Austrian wine

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Abstract: 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 5380 L. 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 L 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 CO_2e. The GHG emissions for the production of a wine bottle in Austria causes 0.328 kg CO_2 equivalent emissions. The GHG emissions for washing (0.011 kg CO_2 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 L 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 4367 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.

Keywords: GHG emission; carbon footprint; lightweight bottles; reuseable bottles; refilling wine bottles

1. 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) [1]. Comparably, China also intends to reduce the CO_2 emissions from 2030 onwards and to achieve e.g., carbon neutrality by 2060 [2]. 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 [1]. Achieving carbon neutrality and reducing carbon emissions is a major challenge. To avoid the large amounts of carbon emissions caused by the extraction and utilisation of oil resources, countries around the world are developing new energy sources, and wind energy is one of them. As far as wind power generation is concerned, predecessors [3] have already done a lot of research.

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 CO_2 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 [4].

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 CO_2-equivalent emissions (CO_2e). CO_2 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 CO_2 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 [5].

CO_2 equivalents are given in units of weight per reference value e.g. g CO_2e/kWh electricity, g CO_2e/kWh natural gas, g CO_2e/kWh gasoline, g CO_2e/km mileage or kg CO_2e/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 (CO_2), methane (CH_4), nitrous oxide (N_2O), 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 [6–8] enjoyed broad adoption and acceptance around the globe by businesses, NGOs, and governments. Many industries, 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:

1) Scope 1 comprises the direct emissions caused by a company itself.
2) Scope 2 includes the emissions from the generation of purchased electricity, steam, heat and cooling consumed by the organization.
3) 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 [9,10].

The determination of the carbon footprint (CFP) of products is standardised in ISO [11], 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 [11]. In many regions, agricultural production is affected by extreme variations and rising temperatures and increasing intensity of extreme weather events. On the other hand, agriculture was responsible for 13%–21% of global anthropogenic emissions of GHG in the years 2010–2019 [12].

The GHG balance of the viniviticultural sector is also topic of methodical recommendations of OIV [13]. 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) [14] or 0.5% of greenhouse gas emissions (calculated using the "climate footprint") [15].

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 CO_2 equivalents, which is 43.11% of the total global warming potential [16]. Gazulla et al. [17] 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 CO_2 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 CO_2e per kg grapes or 0.47 ± 0.17 kg CO_2e 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 CO_2e 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 CO_2e per L were added. In total, a carbon footprint of about 1.7 and 1.9 kg CO_2e per L of wine (without and with transport, respectively) was calculated for Traisentaler Wein for the entire product life cycle from the vineyard to the customer" [18].

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 [19,20].

Taking previous studies on the carbon footprint of fruits and vegetable crops [21] as well as in administration [22] 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 [20].

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 [20,23]. The focus of this paper is the question of the footprint per hectare of vineyard, per L of bulk wine and per 0.75-L 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.

2. Material and methods

2.1. 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:

1) Cradle-to-Grave: Includes emissions and removals that occur throughout the life of the product.
2) 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 (0.75-L bottle).

2.2. 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 [24].

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 [24].

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 [25]. All calculations illustrated in the current study have been performed using this model.

2.3. 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 L 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).

2.4. 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 9000 kg and wine yield of 6750 L 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. The bottle causes the highest GHG emissions (47%) followed by fertilization (12%), tractor energy consumption et cetera (more details of the calculation is published in [20,23].

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
Bottling-Energy	600	kWh conventional electricity
Bottle	8370	pieces „Bordeaux 480 g"
Closures	25.1	kg aluminum capsules
Labelling	15.7	kg paper
Packaging	488.25	kg cardboard cases

For the bottling of the wine produced in one ha of vineyard, 8370 0.75 L Bordeaux-style/claret bottles with a net weight of 480 g are assumed in the calculations. Packaging (488.25 kg for the cardbord 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 L) are included in the system limit.

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

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

Our previous study revealed that the glass bottle accounts for 47% of the CO_2 footprint generated during production [20]. 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-returnable 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

Table 2. (*Continued*).

Small packaging	Technical description	Number of possible refills
Disposable bottle (international)—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/0.75-L 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/0.75-L bottle is assumed.	1

2.5.2. 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, 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 A) and comparatively for the cleaning and filling of returnable glass bottles (Appendix B).

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%.

3. Results and discussion

3.1. 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 6591 kg CO_2 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 6277 L (6750 L minus 7% loss), the KPI of a winery is 0.91 kg CO_2 equivalent emissions per L of bottled wine (or 0.68 per 0.75-L bottle). Grape production accounts for 1733 kg CO_2 equivalent per ha. Assuming a yield of 9000 kg per ha, 1 kg of grapes would cause 0.19 kg CO_2e.

The biggest share of the emissions, namely 3119 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.

Table 3. Greenhouse gas emissions in kg CO_2eq per scope, per area and in total for a model winery in Austria.

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	-	-	3119	3119	kg	48.0
Closures+labels+cardboard cases	-	-	710	710	kg	10.9
Sum	627	515	5354	6496	kg	100
Share in %	9.7	7.9	82.4	100	%	-

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 6277 L 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 L 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 L per hectare [26]. Compared to the assumptions for the model vineyard outlined above, the lower harvest can be filled in 7174 instead of 8370 bottles. Based on the 5-year yield average GHG emissions amount to 5771 kg per hectare and 1.04 kg of CO_2-equivalent emissions per L of wine. One kg of grapes would therefore cause 0.24 kg of CO_2e.

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

3.2.1. 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 [20]. 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_2 emissions are saved for every 10% of used glass in new bottle production [27]. 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).

3.2.2. 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 L of wine in accordance with Table 2.

Container type	GHG emissions in kg per small container unit	GHG emissions in kg per L	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 L bottle (Austria)	0.287	0.383	0.032
Exclusive returnable 0.600 kg/0.75 L bottle (Austria)	0.466	0.621	0.052
Disposable 0.600 kg/0.75 L bottle (international)-one way	0.570	0.760	0.760
PET bottle (primary materials) kg/0.75 L bottle	0.183	0.244	0.244
PET bottle (secondary materials) kg/0.75 L 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 L 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/0.75-L bottle and a refill rate of 12, GHG emissions are reduced to 4367 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.

3.2.3. 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 CO_2 equivalent emissions per bottle. 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 CO_2 equivalents, compared to the production of one standard bottle (0.75 L, 480 g, Vetropack) 0.328 kg CO_2 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. Since a 0.75 L bottle requires the same amount of energy during the washing process as a 1-L bottle, for example, reference was made to the energy required per bottle in **Table 5**.

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/bottle	kWh heating oil/bottle	Energy consumption in kWh/bottle	GHG emissions kg/bottle	Total GHG emissions in kg/bottle
Thermal fuel oil	0.0088	0.0846	0.085	0.022	0.02832
Electricity input	-	0.0227	0.023	0.006	-

4. Conclusions

The energy and material input in a winery in Austria under the system limit considered in the current study amounts to 6994 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.

Detailed GHG calculations can be found in Appendix C.

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Appendix A

Table A1. Case study washing centre for returnable wine bottle 750 mL @ 10,000 bph.

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 1000 bottles	9.9	5.3	0.4	22.5	0.0	0.0

Source: Krones, Germany.

Appendix B

Table B1. Case study washing and filling centre for returnable wine bottle 750 mL @ 6000 bph.

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)
Bottle 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 1000 bottles	17.7	34.6	0.5	21.7	2.7	0.8

Source: Krones, Germany.

Appendix C

Table C1. GHG emission factors for selected energy sources and materials.

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

Source: GEMIS—Global Emissions Model of Integrated Systems 5.0.