# SUSTAINABLE STRATEGY AGAINST CLIMATE CHANGE BASED ON GREENHOUSE GAS EMISSIONS, ENERGY CONSUMPTION AND USE OF MATERIAL RESOURCES IN AUSTRIAN WINE PRODUCTION

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The Austrian certification instrument "Nachhaltig Austria" ("Sustainable Austria") evaluates all activities in the vineyard and cellar. The aim of this work was to determine whether the activities evaluated were in proper relation to each other. The effects on climate change, based on greenhouse gas emissions (GHG), energy use and material input were investigated using the model GEMIS (Global Emissions Model of Integrated Systems). The use of glass bottles causes the majority of greenhouse gas emissions (GHG) at 47 % and cumulative energy demand (CED) at 48 % in the entire wine production chain. Switching to a light glass bottle offers the possibility of saving about 39 % of GHG and about 19 % of CED. However, the multiple use of glass bottles has an even more positive energy-saving effect. Fertilization accounts for 12 % of GHG emissions in the entire wine production chain, with mineral nitrogen accounting for nearly half of these emissions. The switch from fossil fuel to biodiesel has a reduction potential of 43 % of GHG. Despite higher plant protection product quantities, organic farming has a GHG potential that is about 30 % lower than conventional pesticide control. In winemaking, the conversion to green electricity (according to eco-label 46) leads to a remarkable 93 % reduction of GHG. The use of natural corks has a positive effect of 52 % of the GHG compared to aluminum closures. A significant contribution to climate protection can also be made by the fact that enrichment, e. g. with sucrose, can be dispensed with due to a high natural grape ripeness.
**Keywords:** sustainability, wine, greenhouse gas emissions, cumulative energy demand

**Nachhaltige Strategie gegen den Klimawandel auf der Grundlage von Treibhausgasemissionen, Energieverbrauch und Einsatz von Materialressourcen in der österreichischen Weinproduktion.** Das österreichische Zertifizierungsinstrument "Nachhaltig Österreich" bewertet alle Aktivitäten im Weingarten und Keller. Ziel dieser Arbeit war zu bestimmen, ob die bewerteten Aktivitäten in richtiger Relation zueinander stehen. Die Auswirkungen auf den Klimawandel auf Basis der Treibhausgasemissionen (THG), der Energienutzung und des Materialeinsatzes wurden dabei mit dem Modell GEMIS (Global Emissions Model of Integrated Systems) untersucht. Die Glasflaschenverwendung verursacht den überwiegenden Anteil THG mit 47 % und des kumulativen Energiebedarfs (KEA) mit 48 % in der gesamten Weinproduktionskette. Die Umstellung auf eine leichte Glasflasche bietet die Möglichkeit, rund 39 % der THG und ca. 19 % des KEA davon einzusparen. Die Mehrfachnutzung von Glasflaschen hat jedoch einen noch positiveren Energiespareffekt. Die Düngung trägt 12 % zu den THG-Emissionen in der Weinproduktionskette bei, wobei der Anteil der mineralischen Stickstoffdüngung beinahe die Hälfte beträgt. Der Umstieg von fossilem Treibstoff auf Biodiesel hat ein Reduktionspotential von 43 % der THG-Emissionen. Trotz höherer Aufwandsmenge für Pflanzenschutzmaßnahmen hat eine biologische Bewirtschaftung ein um etwa 30 % geringeres THG-Potential als die konventionelle Pestizidbekämpfung. Bei der Weinbereitung führt die Umstellung auf Ökostrom (gemäß Umweltzeichen 46) zu einer Reduktion von bemerkenswerten 93 % der THG. Die Verwendung von Naturkorken hat im Vergleich zu Aluminiumverschlüssen einen positiven Effekt von 52 % der THG. Einen wesentlichen Beitrag zum Klimaschutz kann auch die Tatsache leisten, dass durch eine hohe natürliche Traubenreife auf eine Anreicherung, z. B. mit Saccharose, verzichtet werden kann.
**Schlagwörter:** Nachhaltigkeit, Wein, greenhouse gas emissions, cumulative energy demand

With the 2015 harvest, the Austrian Winegrowers' Association has provided an online certification tool to promote sustainability awareness in the areas of climate neutrality, energy use, material use, water use, soil fertility, biodiversity, high quality standards, social aspects and economic profitability in Austrian wine production. All activities in the vineyard and in the cellar are evaluated, from the new planting of vineyards to grape production and wine making, each between +10 and -10. This gives each winery the opportunity to learn about sustainable strategies and to obtain the adequate certification by implementing numerous sustainability activities (Rosner et al., 2015).

For the calculation of environmental impacts, life cycle assessment (LCA) databases are used. They contain Life Cycle Inventory (LCI) data or data on individual processes, which are analysed within the framework of a life cycle assessment. Their primary purpose is to enable companies carrying out life cycle assessments to draw on these sources. Various initiatives have been taken to standardize data collection and coding. One of these initiatives is supported by the JRC (Joint Research Center) of the European Commission and is the "International Reference Life Cycle Data System (ILCD)" aiming to develop sustainable consumption and production structures. Priority is given to compliance with ISO 14044 (ISO, 2006) and a common standard is presented with regard to life cycle assessment databases. This standard is called ILCD standard. The JRC has also compiled a list of software tools and a directory of LCA databases.

On behalf of the Swiss Federal Office for the Environment, ESU-services GmbH has investigated the "Environmental impacts of private consumption and reduction potentials" (Jungbluth et al., 2012). The authors found that wine consumption is responsible for 2 % of the ecological footprint (calculated using the ecological scarcity method) and that this is half as high as the share of air travel (approx. 4 %) in the ecological footprint of Swiss households. However, if instead of the ecological footprint only the "climate footprint" is considered, the share of wine consumption is about 0.5 % of greenhouse gas emissions (Podzorski, 2019). In contrast, air travel accounts for over 9 % (Jungbluth, 2019).

The Austrian Greenhouse Gas Inventory (National Inventory Report - NIR; Federal Environment Agency 2019) describes the greenhouse gas emissions (GHG) of viticulture in the category land use and land use change (LULUCF). For the calculation of the biomass in viticulture, Austria-specific data were used for the first time in 2018 and an Austrian average annual carbon accumulation rate in total biomass of 0.096 t carbon (C) per ha was determined and a carbon stock in biomass of 3.37 t C per ha at the end of the rotation period of 35 years was calculated on average (Umweltbundesamt, 2019a). The calculation of soil carbon takes into account that vineyard soils with green cover (erosion control) have a higher annual carbon storage than soils without greening measures.

The Austrian wine industry shows a very high level of environmental awareness by international comparison. With 6,567 ha or 15.5 % of organic cultivation area (Öwm, 2020), Austria is among the world's leaders. While organic farming influences the field of biodiversity mainly in terms of plant protection and fertilization, the "organic regulation" currently hardly mentions any influences on climate change explicitly. This seems all the more important as the degree of mechanization in the vineyard, but also in the cellar, has increased strongly in the last decades. Measures such as soil cultivation, weed control, plant protection, fertilization, canopy management, use of grape harvesting machines, grape processing, fermentation control, winemaking, packaging and bottling have a significant impact on climate change. (Rosner, unpublished) LCA studies show that glass production is the main driver to the environmental impact of the entire wine production process, and that pesticide application, tillage and fertilization also play a significant role in the vineyard (Meneses et al., 2016). This is also confirmed by calculations of the carbon footprint of grape production in the vineyard, which showed that diesel consumption, followed by mineral fertilizers and pesticides, are the biggest polluters. In wine production, the main source of emissions is packaging in the form of the traditional glass bottle (Soja et al., 2010). The life cycle assessments determined for glass bottles, whether refillable or non-refillable, clearly show that the refillable glass bottle pollutes the environment less than the production-intensive non-refillable bottle. The weight of the glass bottle is the main factor determining the environmental impact (Dinkel and Kägi, 2014).

In this work, the activities in the vineyard and cellar regarding climate change in the certification tool "Nachhaltig Austria" (approx. 2,200) were reviewed and the main drivers identified. The aim was to show the effects of targeted measures (changes in management or in the use of inputs) on the greenhouse gas balance and to identify the most effective levers for improving the climate balance in viticulture and wine production. The knowledge gained in the sustainability areas of climate

neutrality, energy and resource use serves as an evaluation basis for the online tool "Nachhaltig Austria". With these new findings, wine production is to be sensitized to critically question practices with regard to environmental impacts. The results of this study should be of interest to a wide range of experts, such as decision makers in the wine industry, members and stakeholders of the grape and wine industry (local and global) who want to improve the ecological profile of wine, as well as researchers in the field of agriculture and sustainability. The results will also provide wine consumers with more informed insights into the environmental impact of their purchasing decisions.
The article is structured as follows: An average Austrian winery is compared to a winery with changed input and management parameters (e. g. conventional vs. organic production, standard glass bottles vs. light glass bottles, etc.) and the effects on the carbon footprint and energy balance are determined according to the "Global Emissions Model of Integrated Systems" (GEMIS). The comparison of important activities in the vineyard and the cellar should make recommendations derivable and should be incorporated into the certification tool "Nachhaltig Austria" in order to improve the climate balance in Austrian viticulture.

## MATERIALS AND METHODS

For the preparation of life cycle assessments, the GEMIS model (Global Emissions Model of Integrated Systems; appears in the JRC list as a recognized database) was used in the project, which is maintained for Austria by the Federal Environment Agency (Umweltbundesamt, 2019b). GEMIS is a computer-based instrument with which the environmental impacts of different systems and processes can be calculated and compared in a simple, precise and above all comprehensive way. GEMIS takes into account all essential processes, starting with primary energy and raw material extraction, through useful energy and material supply, e. g. also auxiliary energy and material input for the production of energy plants and transport systems, and thus offers the possibility of considering not only direct emissions but also upstream process emissions.
As another reliable generic database, the ecoinvent database (appears in the JRC list as a recognized database (Ökobilanzdatenbank, 2020)) was also accessed to verify the data from GEMIS.

### SYSTEM LIMIT

The planting, cultivation, harvesting and bottling of one hectare of wine was studied on the basis of two different management systems, which include the following data: As a basis, a climate balance for an average Austrian winery ("Winery 1") was estimated by means of GEMIS in order to map the greenhouse gas (GHG emissions) of each criterion and to show which measures have the strongest impact on GHG emissions. The parameters serve to classify the bandwidth of the results. In addition, a comparative climate balance was estimated for a winery ("Winery 2") with changed input and management parameters. The two different management systems were called "Winery 1" and "Winery 2" (Tables 1 and 2). What both have in common is that the infrastructure (cellar buildings, residential buildings, machines) and the distribution logistics lie outside the system boundaries.

### CARBON FOOTPRINT - DIRECT AND UPSTREAM GREENHOUSE GAS (GHG EMISSIONS)

The calculation of the carbon footprint considers direct and upstream emissions, which were calculated by multiplying the input data with emission factors. Direct emissions are those that arise directly from combustion processes, while (temporally) upstream emissions include all emissions from combustion processes in the upstream chain (e. g. raw material/energy source extraction, intermediate processing, transport, etc.). For the Austrian specific data, the emission factors of direct greenhouse gas emissions are compared with the current Austrian greenhouse gas inventory (Umweltbundesamt, 2019a). For indirect greenhouse gas emissions, the upstream emissions are compared with emission factors from the GEMIS Austria database.

### ENERGY BALANCE INCLUDING THE USE OF OPERATING RESOURCES

For the calculation of $CO_2$ emissions, all relevant energy and material inputs are defined and considered. There is therefore a direct link between the energy balance and the climate balance. The system boundaries are identical as described in the section GHG emissions.
The cumulative energy demand (CED) considers the

| **Vineyard infrastructure** | **4349[1]** | **kg of steel (poles, stakes and wire)** |
|---|---|---|
| **Planting** | 3570[2] | vines |
| **Tractor energy consumption** | 1375[3] | kWh diesel (around 135 litres) |
| **Plant protection** | 10,5[4] | kg plant protection products (conventional) |
| **Fertilization** | 155[5] | kg mineral fertilizer (40 kg N, 70 potassium, 20 kg phosphorus, 25 kg magnesium) |
| **Enrichment** | 175[6] | kg sucrose |
| **Treatment agent** | 13[7] | kg (must and wine treatment agent) |
| **Wine storage - energy** | 1600[8] | kWh conventional electricity |
| **Bottle filling - energy** | 600[9] | kWh conventional electricity |
| **Wine cellar - energy** | 200[10] | kWh conventional electricity |
| **Bottle** | 9000[11] | pieces Bordeaux 375 g |
| **Closures** | 9[12] | kg aluminium capsules |
| **Labels** | 2[13] | kg paper |
| **Packaging** | 236[14] | kg boxes |

[1] The calculation includes 3,570 training stakes of 0.2 kg each, 715 vine poles of 5 kg each and 6,000 meters of wire with 0.01 kg/rm (FUHRMANN, 2020).

[2] The funding guidelines for the "Restructuring and conversion of vineyards" permit a maximum of 2.8 m² of standing space per vine (row width × vine spacing in the row), which was used as the basis for calculation (AMA, 2020).

[3] Use of average net expenditure according to data „Nachhaltig Austria“

[4] 7 applications, each application 1.5 kg of plant protection products (REBSCHUTZDIENST, 2020a)

[5] fertilizer applications per hectare of vineyard area using mineral fertilizer; 40 kg pure nitrogen, 70 kg potassium, 20 kg phosphorus, 25 kg magnesium (fertilizer guidelines of good agricultural practice; BMLRT, 2020a)

[6] For the enrichment of 6,750 liters of must, 175 kg were accepted in wine-growing zone B.

[7] Must and wine treatment agents of 6,750 liters from harvest to bottling: 1 kg PVPP (polyvinylpolypyrrolidone), 2 kg diatomaceous earth, 3 kg pure yeast, 6 kg liquid gelatine, 0.5 kg activated carbon, 0.5 kg enzymes

[8] Assumption: electricity input of 800 kWh for cooling 9,000 bottles

[9] Assumption: 600 kWh electricity for 9,000 bottles (300 kWh for pumps, filter system and presses, 300 kWh electricity for washing bottles)

[10] Assumption: 200 kWh electricity for filling 9,000 bottles

[11] Quantity with acceptance of a maximum yield per hectare of 6,750 liters

[12] For 9,000 BVS ("Bague Vin Suisse") capsules, a secondary aluminum content of 40 % is assumed, which means 9.4 kg aluminum (rounded 9 kg)

[13] The paper insert for 9,000 labels is estimated at 2 kg.

[14] Cardboard box with 6 bottles estimated with 157 g per box; for 9,000 bottles resulting in 235 kg

Table 2: Input data "Winery 2"

| Vineyard infrastructure | 4349 | kg of steel (poles, stakes and wire) |
|---|---|---|
| Planting | 3570 | vines |
| Tractor energy consumption | 1375[1] | kWh diesel (around 135 litres) |
| Plant protection | 30[2] | kg plant protection products (organic) |
| Fertilization | 115[3] | nitrogen addition by green manure, rest by mineral fertilizer (70 kg potassium, 20 kg phosphorus, 25 kg magnesium) |
| Enrichment | 0[4] | kg sucrose |
| Treatment agent | 0[5] | kg (must and wine treatment agent) |
| Wine storage - energy | 1600[6] | kWh conventional electricity |
| Bottle filling - energy | 600[6] | kWh conventional electricity |
| Wine cellar - energy | 200[6] | kWh conventional electricity |
| Bottle | 9000[7] | pieces Bordeaux 375 g |
| Closures | 13[8] | kg natural cork |
| Labels | 2 | kg paper |
| Packaging | 236 | kg boxes |

[1] In contrast to "Winery 1" not diesel but biodiesel was calculated.
[2] 10 applications, per application 3 kg plant protection products are assumed (elementary spray agents such as sulphur and copper) - (REBSCHUTZDIENST, 2020b)
[3] fertilizers per hectare vineyard using mineral fertilizer: 70 kg potassium, 20 kg phosphorus, 25 kg magnesium; nitrogen is provided by green manure (BMLRT, 2020a)
[4] Musts are not enriched due to the high natural grape ripeness.
[5] Must and wine are not subjected to wine treatment.
[6] The electricity used in the cellar (processing and pumps) for storage and bottling is provided by green electricity certified with the 46 eco-label.
[7] Lightweight glass is used for bottling, which, at 230 g, requires 39 % less material per bottle than an average traditional wine bottle.
8 "Winery 2" uses natural corks, which means a material input of 13 kg for 9,000 bottles.
In addition to the data, a survey of a professional bottle cleaning company will be carried out to determine the effects of bottle cleaning and thus the use of recyclable bottles as an alternative to "light glass" and "normal glass".

sum of all primary energy inputs over the entire life cycle in the vineyard and cellar. The energy input for the production of goods is one of the essential factors for the sustainable design of products and services.
As with the carbon footprint (CFP), the purpose of calculating the CED is not so much to obtain a single figure as to compare the individual contributions over the entire life cycle of the product. Thus, as in the calculation of the carbon footprint, in the following two wineries ("Winery 1" and "Winery 2") with different energy and material inputs are compared under the aspect of cumulative energy consumption.

## RESULTS AND DISCUSSION

### CARBON FOOTPRINT - DIRECT AND UPSTREAM GHG EMISSIONS

The calculation results show the effects of energy and material use on greenhouse gas emissions.
As shown in Figure 1, the bottle causes the highest GHG emissions (47 %) in "Winery 1 followed by fertilization (12 %).The use of nitrogen by mineral fertilizers leads to two greenhouse gas effects. On the one hand, the Haber-Bosch process enables the synthetic production of nitrogen fertilizer. However, this requires a high energy input, which leads to corresponding greenhouse gas emissions. On the other hand, nitrous oxide emissions are released during the application of nitrogen, which have an extremely higher greenhouse gas potential than $CO_2$ (approx. 300 times higher).

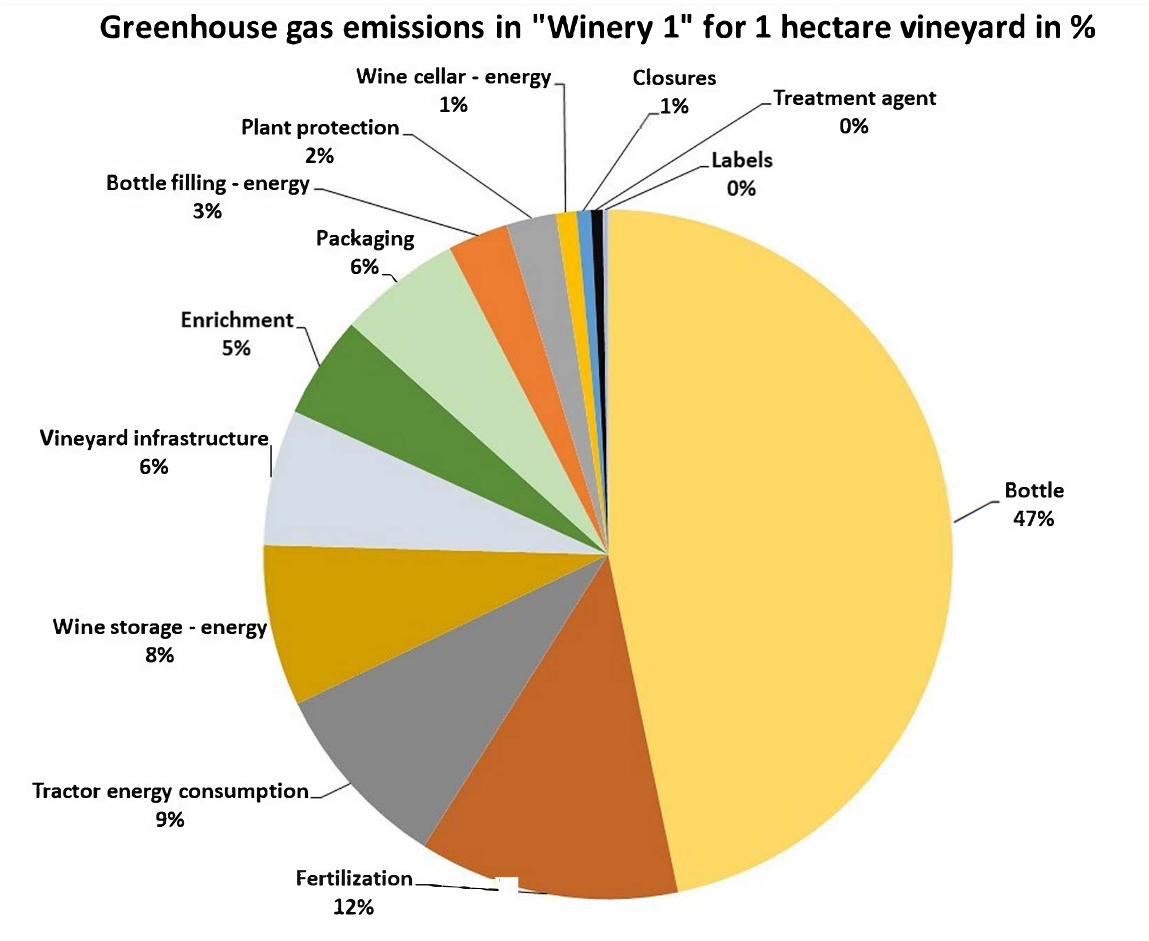


Fig. 1: Greenhouse gas emissions in "Winery 1" for 1 hectare of vineyard area in %

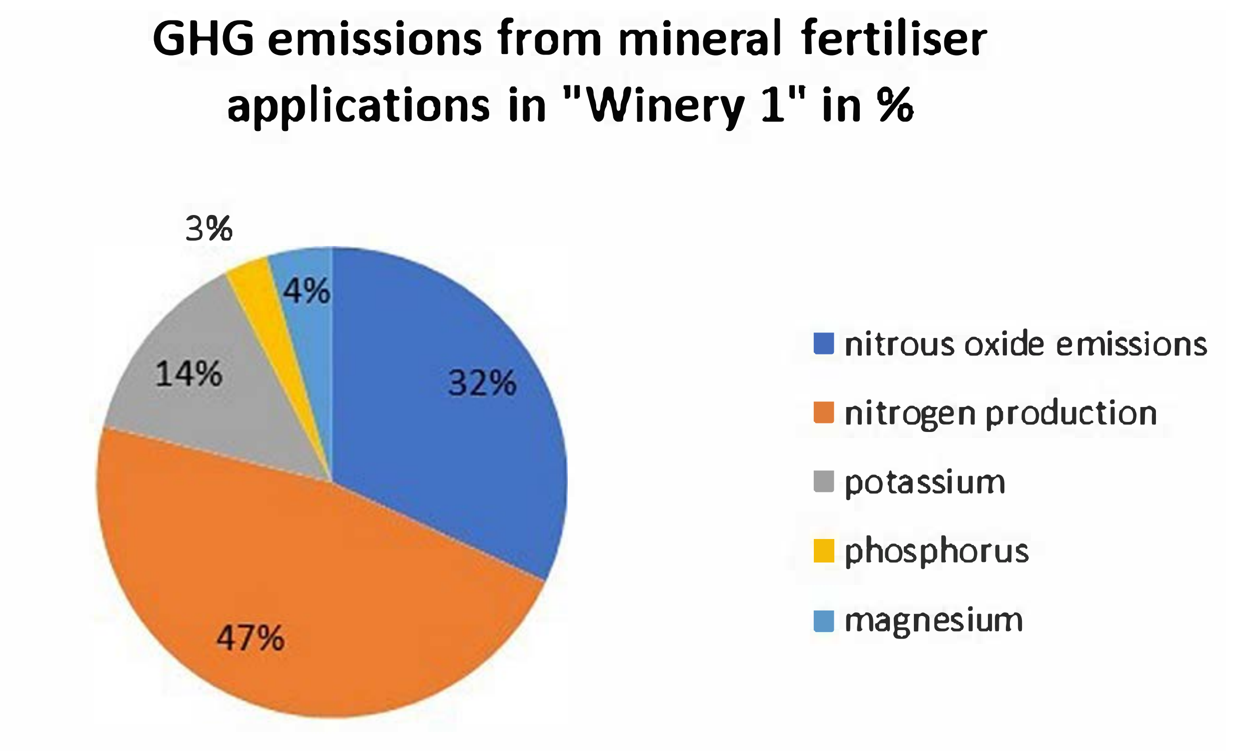


Fig. 2: Greenhouse gas emissions from the application of mineral fertilizers in "Winery 1" in %

Figure 2 shows the sectors from which GHG emissions from mineral fertilizer applications originate. About 47 % of the GHG emissions from mineral fertilizer applications come from nitrogen production. About one third of the emissions are caused by nitrogen oxide in the vineyard. Potassium, phosphorus and magnesium production are responsible for about 21 % of the total GHG emissions in this sector.

Another major emitter of GHG (about 9 %) is the combustion of fossil diesel in tractors used for work in the vineyard (until harvest). The energy used to control the temperature of the wine warehouse accounts for about 8 % of total GHG emissions. The electricity consumed in the wine cellar represents about 3 %, while bottling accounts for about 1 %. Thus, the total electricity used in "Winery 1" represents about 12 % of the total GHG emissions. The use of steel poles, stackes and wires with a life cycle of 30 years represents about 6 % of the total GHG emissions. The production of cardboard boxes (6 bottles/box) to sell 9,000 bottles in standard units is responsible for about 6 % of the total GHG emissions. The enrichment of 6,750 liters by 2 °KMW requires 175 kg of sugar, which accounts for about 5 % of the total GHG emissions. The shares of plant protection (about 2 %), bottle closures (BVS capsules, about 1 %), labels and wine treatment agents in the total emissions are comparatively very small.

The energy and material input of "Winery 2" differs from that of "Winery 1" in a number of key areas, as Figure 3 clearly shows.

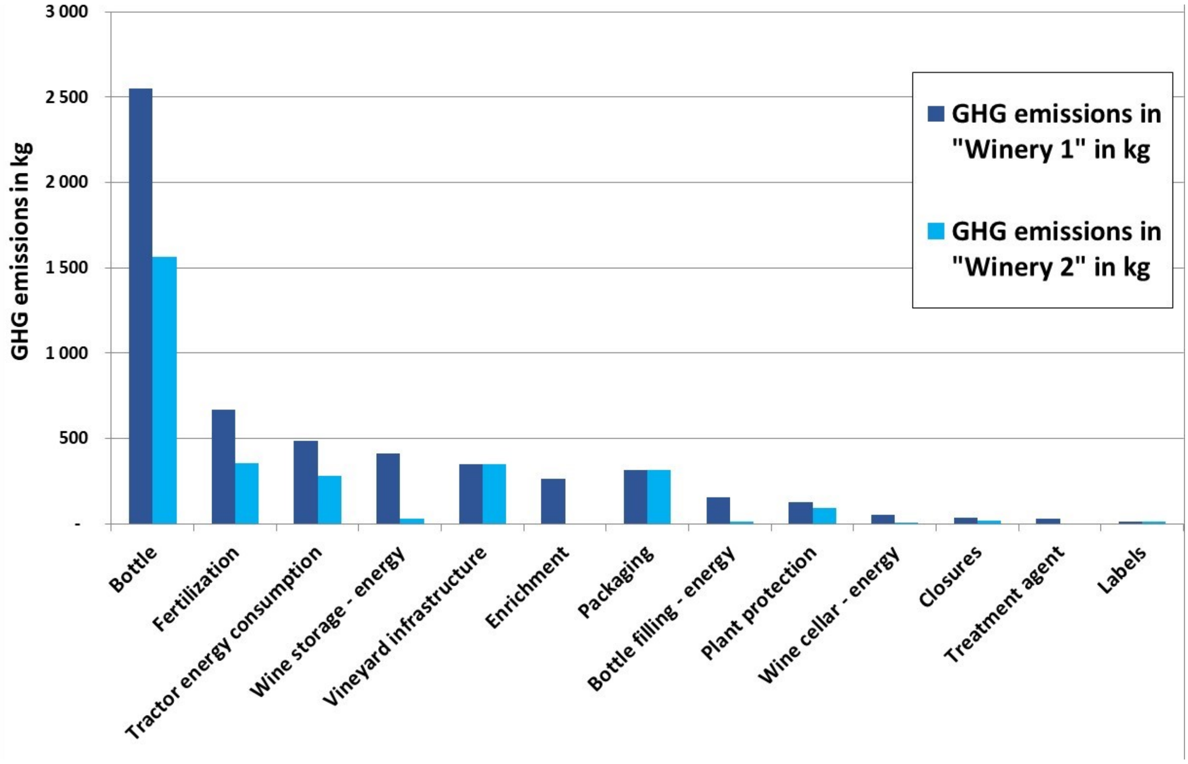


Fig. 3: Savings potential of greenhouse gas emissions of "Winery 1" compared to "Winery 2" for 1 ha of vineyard area (in kg) in descending order of importance

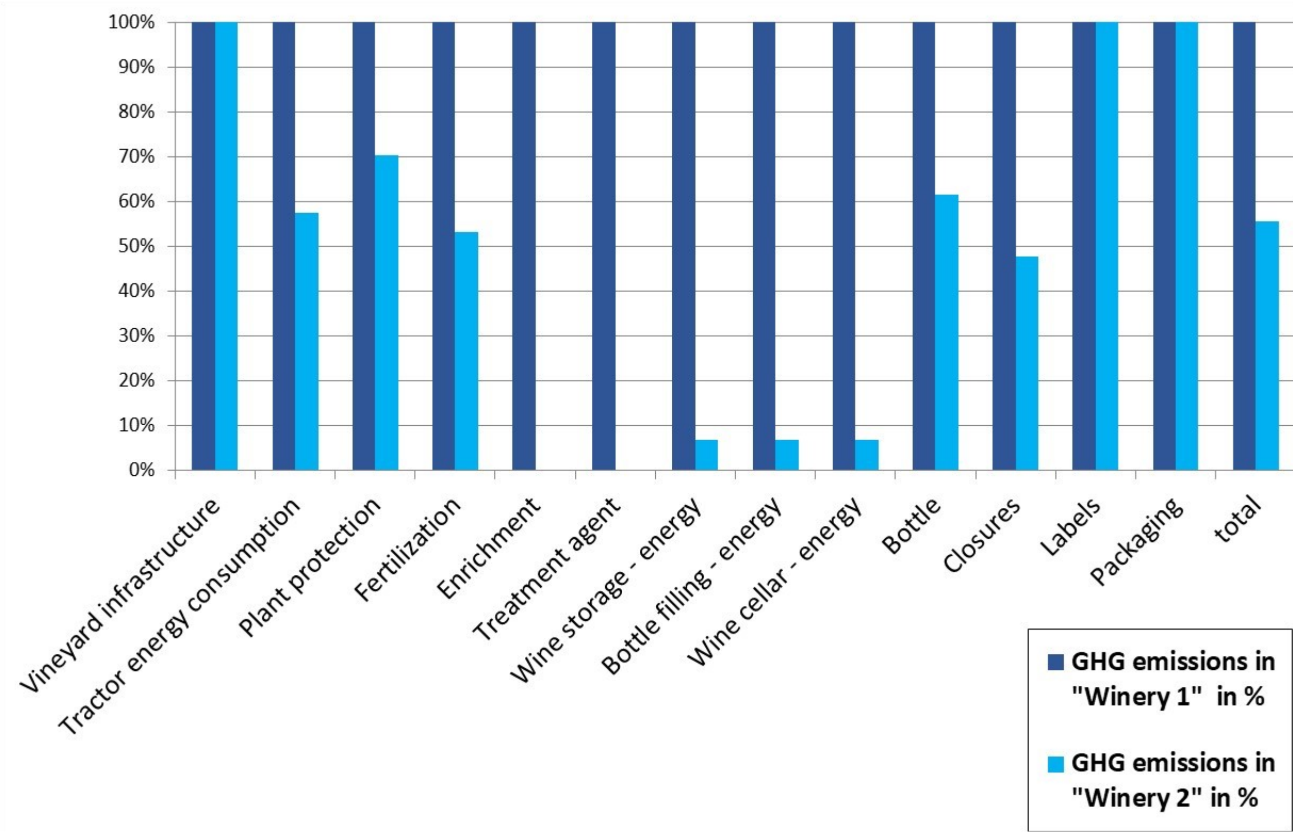


Fig. 4: Reduction of GHG emissions of selected areas with the fixation of Winery 1 at 100 % each compared to “Winery 2”

As illustrated in Figure 4 the greenhouse gas emissions of "Winery 2" with respect to the bottle are reduced by about 39 %. Due to the green manure of "Winery 2" it is assumed that no nitrogen is applied with mineral fertilizer. Thus, 47 % emissions can be saved by this measure. The use of biodiesel results in about 43 % less GHG emissions. The use of green electricity in accordance with eco-label 46 reduces $CO_2$ emissions by about 93 % for the same energy input. The electricity mix of green electricity is 100 % renewable compared to conventional Austrian electricity, which explains the GHG reduction potential. Plant protection in conventional production ("Winery 1") leads to higher GHG emissions during production compared to plant protection products for organic farming ("Winery 2"). For this reason, the emissions in "Winery 2" are reduced by about 30 % compared to "Winery 1", although higher application rates and times are necessary in organic production. Compared to aluminium closures, natural cork causes significantly lower GHG emissions and accordingly leads to an emission reduction of about 52 % in "Winery 2".

In summary, under the assumptions made, a reduction of the total GHG emissions of "Winery 2" compared to "Winery 1" of about 45 % can be determined.

## ENERGY BALANCE INCLUDING THE USE OF OPERATING RESOURCES

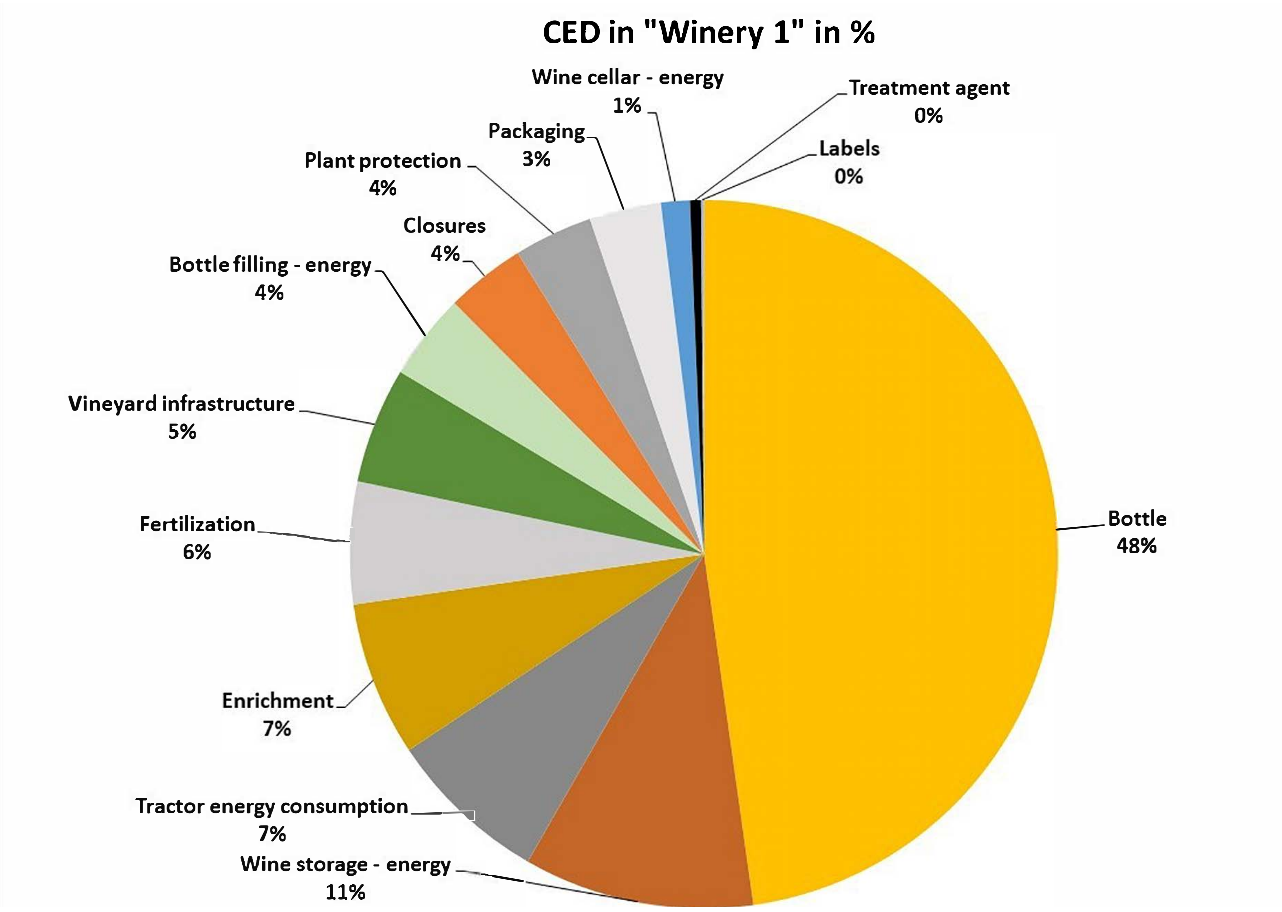


Fig. 5: Cumulative energy requirement (CED) in kWh for "Winery 1" shown for 1-ha vineyard

As illustrated in Figure 5 the glass bottle accounts for 48 % of the energy input (cumulative energy requirement = CED) in "Winery 1". The storage of wine makes up 11 % leading to the second highest energy input in "Winery 1". Regardless of its origin, the use of electricity leads to high CED values. Subsequently, the tractor work to cultivate a 1-hectare vineyard until grape harvest requires a diesel input that accounts for 7 % of the CED. The enrichment on a scale of 2 °KMW of 6,750 liters wine (0,75 % wine yield of 9,000 kg grapes) leads to a 7 % increase of the CED of "Winery 1". The energy intensive process of nitrogen production for the production of mineral fertilizer causes 6 % of the CED of "Winery 1". The use of steel for stakes, poles and wires, based on a 30-year life period, accounts for 5 % of the CED (vineyard infrastructure). The electricity used for washing and bottling is assumed to be 600 kWh for the "Winery 1" system, which represents about 4 % of the CED. The material input of 9 kg aluminium closures and 10 kg conventional pesticides is in the same order of magnitude. In terms of material input for packaging, CED accounts for about 3 % of the total energy input. Energy consumption in the cellar, labels and wine treatment accounts for about 1 % of the total CED of "Winery 1".

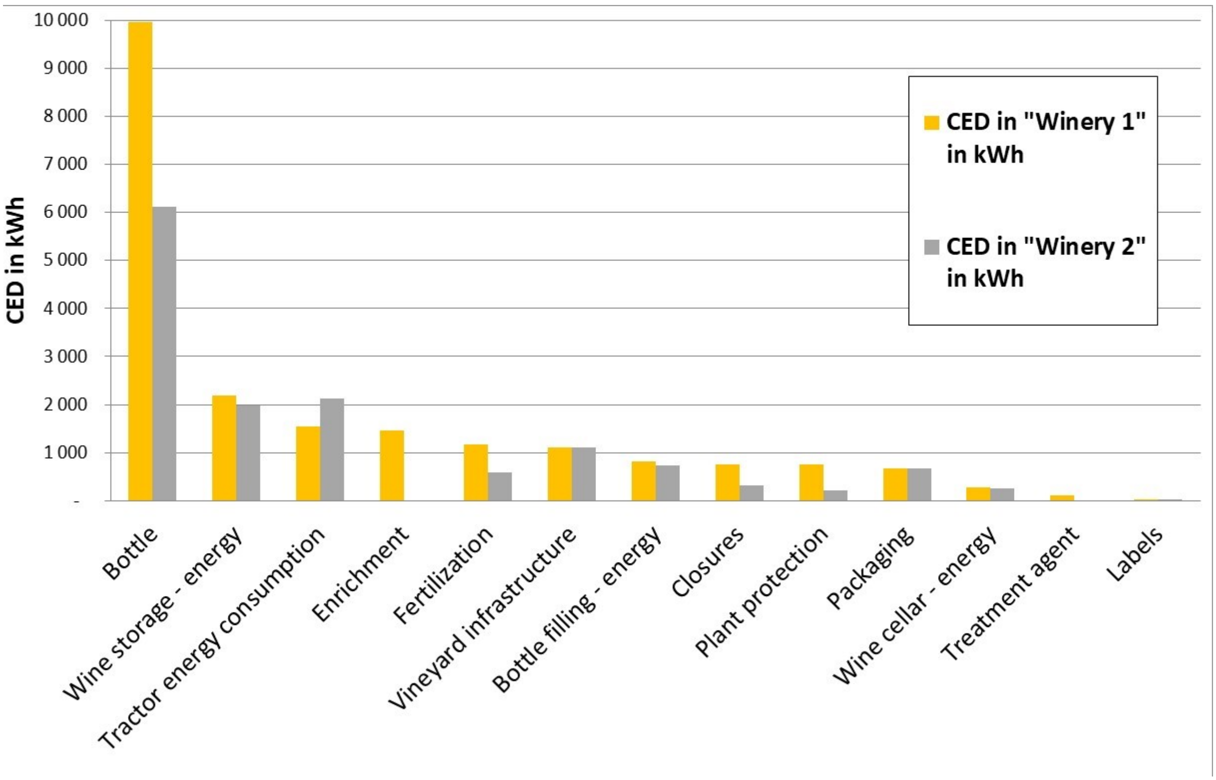


Fig. 6: Savings potential of the CED of 1-ha vineyard of "Winery 1" compared to "Winery 2" (in kWh)

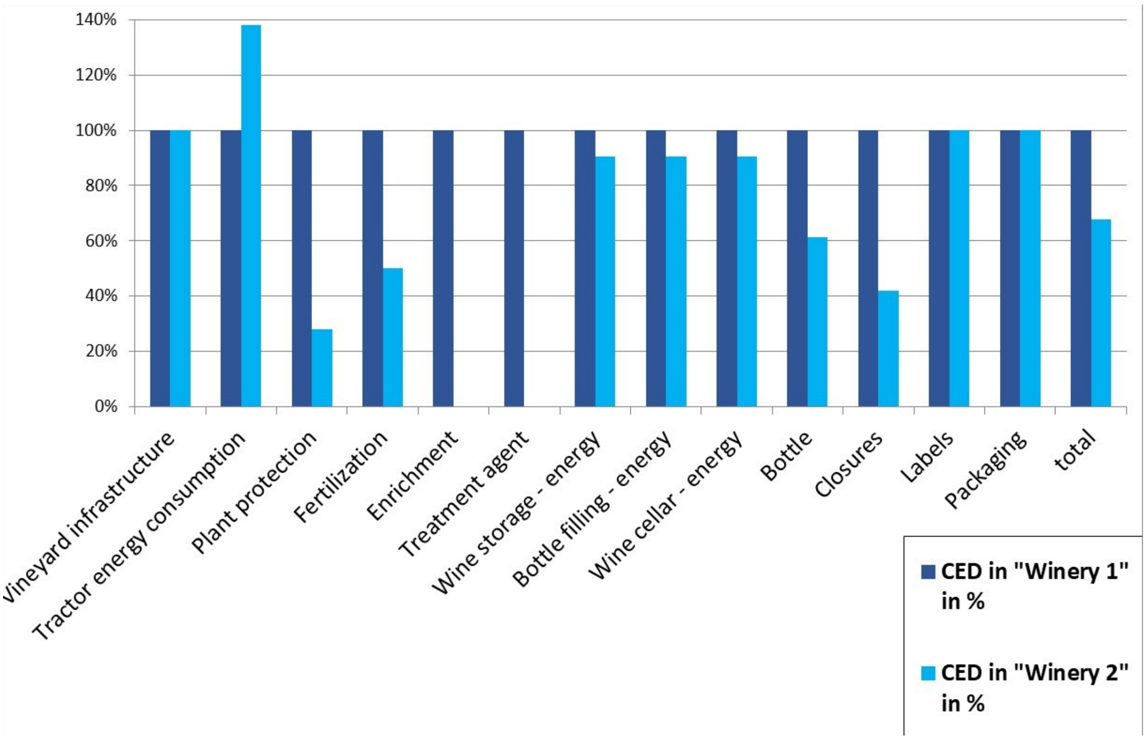


Fig. 7: CED in % of 1-ha vineyard area of "Winery 1" compared to "Winery 2"

As illustrated in Figures 6 and 7 the CED in "Winery 2" is reduced by about 39 % due to the use of lightweight glass bottles. The electricity mix from green electricity (according to eco-label 46) leads to a slight reduction of the CED by about 9 % compared to conventional Austrian electricity. The leverage effect of renewable energy sources is much lower than for greenhouse gas emissions. Renewable energy sources are limited in terms of energy conversion (efficiency) and energy density compared to fossil fuels. Only hydropower has advantages over fossil fuels due to the high proportion of electricity generated by the CED. Since the majority of the electricity generated in the IP-46 is hydroelectric, there is a slight reduction in CED in "Winery 2" compared to conventional electricity in "Winery 1". Regarding the energy input of the tractor, the use of biodiesel leads to an approx. 38 % higher CED ("Winery 2") compared to fossil diesel. The cultivation with green manure in "Winery 2" means that no nitrogen has to be applied with mineral fertilizer. This results in a 50 % saving. Plant protection with "conventional" methods leads to higher CED during production compared to plant protection products for organic farming. For this reason, the CED for "Winery 2" is reduced by about 72 % as compared to "Winery 1", although higher application rates are required. Natural cork causes a lower CED compared to aluminium closures. Therefore, "Winery 2" can expect a reduction of the CED by about 58 % in the area of "closures"

For the assumptions above, the total CED of "Winery 2" is reduced by about 32 % compared to "Winery 1".

The survey at an exemplary bottle cleaning plant in Lower Austria suggests that there is an enormous savings potential in the multiple use of glass bottles instead of using new glass. No calculations were made.

## CONCLUSIONS

Glass bottles cause about 47 % of the total GHG emissions in the entire production chain (48 % of the CED). The material consumption is substantial, correspondingly high are the emissions from the production of the bottles are high (assumption glass bottle Bordeaux 0.75 l with 375 g weight). However, many high-quality wines and sparkling wines are filled in even heavier bottles (e. g. Bordeaux Grand Cru 0.75 l with 984 g or "Collio" 0.75 l with sparkling wine neck with 720 g weight). Fillings in smaller glass bottles also have a higher bottle weight in relation to the content (e. g. Bordeaux 0.187 l with 165 g bottle weight) (Vetropack, 2020).

In contrast, the use of "lightweight glass" leads to lower greenhouse gas emissions:

- reduction of total GHG emissions for "Winery 1" by 18 % (19 % CED)
- reduction of total GHG emissions for "Winery 2" by 25 % (27 % CED).

In addition to the use of lightweight glass, the multiple use of glass bottles is a strong greenhouse gas reducing alternative. Only 0.3 to 0.5 l water, approx. 1 g detergent (caustic soda + surfactants) and 40 W energy (thermal) per bottle are required for cleaning and refilling the glass bottles. In contrast, a new glass bottle requires a smaller amount of water for rinsing before bottling (0.10 to 0.15 l per bottle), but this results in a considerable blue and grey water footprint and energy consumption due to the glass production process of the new bottle. The survey of the cited bottle-washer also showed that multiple filling of disposable glass - with the exception of fogging of the glass, which could be eliminated in production - could be a potential saving alternative. Also the screw thread does not seem to pose a hindrance to multiple filling if handled properly if one takes into account the common practice with mineral water bottles. However, further investigations are necessary for a definitive recommendation. The obligatory changeover to a deposit bottle system would lead to massive emission reductions, but would also greatly limit the variety of bottle types.

The energy saving by using natural cork instead of aluminium capsule closures is relatively high. Also the CED for mineral fertilization is much higher than for organic fertilization or green manure.

Green manure can make a contribution to minimizing the climate impact of fertilization, but only if there is no degradation of the nitrogen depot in the soil. In viticulture, cessation of fertilization in the medium term is not a strategy. For long-lasting, vital vineyards and the resulting ripe, sound grapes, it is necessary to ensure a good supply of nutrients to the soil.

The Fuel Regulation (KVO) 2012 enforces the Directive on the Promotion of Renewable Energy Sources (28/2009/EG) (Bmlrt, 2020b). The KVO stipulates biofuels to be added at a rate of 6.3 % for diesel fuel and 3.4 % for petrol. Biofuels must lead to a 6 % reduction in fuel consumption in Austria along the entire value chain. An increase of the admixture could also be discussed as an emission reduction.

It also seems interesting that the CED of the diesel use (tractor energy consumption) in vineyards causes the same amount as the enrichment with sucrose (Fig. 6). The natural ripening of the grapes without enrichment processes thus also contributes highly to the reduction of the CED.

The advantage of renewable energy sources lies in the lower $CO_2$ equivalent emissions compared to the use of fossil fuels. The supply with renewable energy sources (creation of power plants) requires more energy and the energy conversion is not as efficient as with fossil energy sources. The energy density of fossil energy sources is significantly higher than that of renewable energy sources. The use of renewable energy sources leads to a high energy input in the supply, therefore renewable energy sources have to be valued equally with fossil energy sources (Fig. 6 and 7).

The balanced material input for boxes/packaging was calculated from recycled material with average emission factors. About 20 % of the GHG emissions come from the purchase of electricity. Accordingly, there is a savings potential through the use of renewable energy sources, but this is not considered to be very high. Boxes are excluded from the Eco-label Directive (IP-RL) for packaging purposes, i. e. there are no boxes for wine bottles with the IP. Within the scope of the IP-RL for reusable systems, transport units made of cardboard or other materials are permitted if they are functionally reusable several times. Labels contribute hardly any GHG savings potential.

The location of the vineyard and the selection of suitable vine planting material are among the most fundamental decisions for a winery. The assessment of the impact of the vineyard location and the choice of planting material on the CED has shown that this issue has great potential and should still be subject to scientific evaluation. The pesticides, in viticulture mostly fungicides, can be reduced by the use of so-called fungus-resistant grape varieties. That can lead to potential savings of up to 75 % of fungicides. Since the lifespan of a vineyard is 30 to

50 years, a reduction of pesticides can strongly contribute to sustainability. The findings of this work are incorporated into the certification tool "Nachhaltig Austria" and should contribute to the promotion of sustainable activities by grape and wine producers as well as policy-makers.

## REFERENCES

AMA, 2015: Maßnahmenerläuterungsblatt ÖPUL 2015: Maßnahme Erosionsschutz Obst, Wein, Hopfen. https://www.ama.at/getattachment/0543decc-1af6-48ac-94c0-3a6048dfebf1/MEB_Oepul2015_Erosionsschutz_Obst-Wein-Hopfen_3-1.pdf, (18.08.2020)

AMA, 2020: Umstrukturierung und Umstellung von Rebflächen.https://www.ama.at/getattachment/6ba7670b-bf6e-45b7-bec1-3ac78376f693/Merkblatt_W30_Juli_2020.pdf. Stand 2020/07: 9 (18.08.2020)

BMNT, 2017: Die österreichische Strategie zur Anpassung an den Klimawandel. Teil 2 – Aktionsplan, Handlungsempfehlungen für die Umsetzung. Aktualisierte Fassung Jänner 2017. WIEN. ISBN 978-3-903129-47-4

BMLRT, 2020a: Sachgerechte Düngung im Weinbau. https://www.bmlrt.gv.at/land/produktion-maerkte/pflanzliche-produktion/boden-duengung/Bodenschutz.html, (18.08.2020)

BMLRT, 2020b: Biokraftstoffe im Verkehrssektor 2019. Bericht erstellt im Auftrag des Bundesministeriums für Nachhaltigkeit und Tourismus. Wien

DINKEL F. UND KÄGI, T. 2014: Ökobilanzierung von Getränkeverpackungen.Umweltperspektiven2014. https://carbotech.ch/cms/wp-content/uploads/Umwelt_Perspektiven_2014_5_522.pdf, (18.08.2020)

FUHRMANN 2020: http://www.fuhrmann.at/de/weingartenpfahl.php, (18.08.2020)

ISO 14044, 2006: Environmental management — Life cycle assessment — Requirements and guidelines. https://www.iso.org/standard/38498.html (03.09.2020)

JUNGBLUTH, N., ITTEN, R. AND STUCKI, M. 2012: Umweltbelastungen des privaten Konsums und Reduktionspotenziale. http://esu-services.ch/fileadmin/download/jungbluth-2012-Reduktionspotenziale-BA-FU.pdf, (18.08.2020)

JUNGBLUT,N.2019:Klimabilanzvon Kurzstreckenflügen. http://esu-services.ch/fileadmin/download/jungbluth-2019-Kurzbeschrieb-SRF-Kurzstreckenflüge.pdf, (18.08.2020)

MENESES, M., TORRES, C.M. AND CASTELLS, F. 2016: Sensitivity analysis in a life cycle assessment of an aged red wine production from Ctalonia, Spain. Science of the Total Environment 562 (2016): 578

ÖKOBILANZDATENBANK 2020: Ökobilanzdatenbank. https://de.wikipedia.org/wiki/%C3%96kobilanzdatenbank, (18.08.2020)

ÖWM 2020: Weingartenflächen und Flächenanteile der Rebsorten. https://www.oesterreichwein.at/fileadmin/user_upload/PDF/Doku/1._Weingartenflaechen_und_Flaechenanteile_der_Rebsorten.pdf: 29, (18.08.2020)

PODZORSKI, U. 2019: Wein und sein Klima-Fussabdruck. Schweizer Zeitschrift für Obst- und Weinbau 14/2019: 8-10

REBSCHUTZDIENST 2020a: https://rebschutzdienst.at/weinbauempfehlungen/pflanzenschutz/applikationsabstaende/, (18.08.2020)

REBSCHUTZDIENST 2020b: https://rebschutzdienst.at/weinbauempfehlungen/pflanzenschutz/hektaraufwand/, (18.08.2020)

Rosner, F.G., Dobritzhofer, W., Geyrhofer, A., Glatt, J., Grossauer, S., Pöchtrager, S., Regner, F., Sauberer, N., Scheiblhofer, H., Sellner, H., Sojy, G., Vogl, K. and Zehetner, F. 2015: Assessment of sustainability in Austrian wine production. 38th World Congress of Vine and Wine: 2015:5-10

Soja, G., Burger, E., Dockner, V., Gerzabek, M., Grünberger, S., Hackl, K., Haslinger, J., Hofmann, R., Kühnen, L., Mehofer, J., Omann, I., Rampazzo Todorovic, G., Rodriguez-Pascual, R., Schildberger, B., Vogl, K. and Zehetner, F. 2019: Weinbau im Klimawandel: Anpassungs- und Mitigationsmöglichkeiten am Beispiel der Modellregion Traisental. https://www.dafne.at/dafne_plus_homepage/index.php?section=dafneplus&content=result&come_from=&&search_fields[title_ger]=Weinbau+im+Klimawandel%3A+Anpassungs-+und+Mitigationsm%C3%B6glichkeiten+am+Beispiel+der+Modellregion+Traisental&search_fields[projektleiter]=&search_fields[antragsteller]=&search_fields[research_objective]=&search_fields[beauftragungsjahr]=&search_fields[offer_number]=&search_fields[keywords]=&search_fields[antragsteller_2]=&project_id=3018, (18.08.2020)

Umweltbundesamt 2013: REFUREC Ireland workshop - Regulation of biofuels in AUSTRIA, National certification scheme & monitoring system (elNa). http://www.refurec.org/workshop/2013-ireland/, (03.09.2020)

Umweltbundesamt 2019a: Austria´s National Inventory Report 2019. Submission under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Wien, 2019 Reports, Band 0677. ISBN: 978-3-99004-496-4.

Umweltbundesamt 2019b: Results from GEMIS (Global Emissions Model for integrated Systems) a public domain life-cycle and material flow analysis model and database. unpublished

Vetropack (2020): https://katalog.vetropack.com/catalogue/result/global/WI#ph=1, (18.08.2020)

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