Wine Economics and Policy

Firenze University Press
www.fupress.com/wep

OPEN ACCESS

Citation: Stefano Massaglia, Tibor Verduna, Vincenzo Varchetta, Filippo Brun, Simone Blanc (2023). The impact of alternative packaging on the life cycle of wine on tap. *Wine Economics and Policy* 12(1): 51-62. doi: 10.36253/wep-13016

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing Interests: The Author(s) declare(s) no conflict of interest.

The impact of alternative packaging on the life cycle of wine on tap

Stefano Massaglia[1], Tibor Verduna[1], Vincenzo Varchetta[2], Filippo Brun[1], Simone Blanc[1,*]

[1] *Department of Agricultural, Forest and Food Sciences, University of Turin, Largo Paolo Braccini 2, 10095 Grugliasco, Italy*
[2] *Quality Assurance Department, Vinicola Agriflegrea, via Nelson Mandela 95, 80126, Napoli, Italy*
E-mail: stefano.massaglia@unito.it; tibor.verduna@unito.it; vincevarchetta@gmail.com; filippo.brun@unito.it; simone.blanc@unito.it
*Corresponding author.

Abstract. Sustainability is a key objective of development policies within international organizations, and it is also progressively gaining importance in the wine industry as a whole and, more specifically, in the draught wine market. The competitive conditions of the wine sector and the evolution of consumption styles have led to an increasing need for more accurate management strategies and analysis activities to determine the performance of wineries. This study aims to analyse both the environmental and the economic concerns of a commercial development strategy implemented by an Italian winery that uses three packaging formats (glass bottle, one-way PET keg, and reusable steel keg) in the sale of Falanghina PGI wine on three different markets (domestic, Italy; regional, Germany; and international, USA). By assessing the environmental and economic impact of the different formats on the three scenarios through LCA and LCC analysis, it is revealed that the economic and environmental sustainability of packaging types can vary significantly depending on the market destinations. In any case, the results show that PET, and especially reusable materials such as steel, can lead to a marked reduction in impacts on the market for tapped wine.

Keywords: Life Cycle Assessment (LCA), Life Cycle Costing (LCC), wine, packaging.

1. INTRODUCTION

Sustainability is undoubtedly a key objective of development policies within international organizations. The European Union (EU), through its *Europe 2020 Strategy*, aims to promote smart, sustainable, and inclusive growth. Sustainability has also gained importance in the wine sector and has led to companies and consumers being more aware of this issue within the wine supply chain [1,2].

Consumer awareness in particular plays a central role in encouraging wine producers to pay close attention not only to economic aspects but also to the environmental impact of wine at different stages of its life cycle [3].

About 258 million hl of wine were produced during the 2019 campaign, according to the International Organisation of Vine and Wine (http://www.oiv.int). Moreover, competitive landscapes in the wine sector and high fragmentation of consumer behaviour have led to the need for management planning and tighter monitoring of costs. The precise estimation of the production cost of a litre of wine is an essential basis for setting up the different processing steps and for developing appropriate marketing strategies [4–6].

The consumption of wine at entertainment venues such as restaurants and bars highlights the need to find a compromise between environmental and economic costs, in order to ensure the consumer has a pleasant, reasonably-priced and sustainably-valued consumption experience. To this end, the choice of wine packaging can impact significantly on limiting environmental impacts and reducing costs. In recent years, several alternative packaging options have been adopted in the beverage sector. In addition to traditional glass bottles, wine is marketed to on-premise markets in large bag-in-box containers, PET (polyethylene terephthalate) kegs, and steel kegs [7].

Two distinct and contrasting aspects arise in the choice of packaging: on the one hand, retailers prefer large-volume packaging due to its convenience; on the other, consumers prefer glass-bottled wine due to environmental concerns about plastic pollution [8]. Another important aspect, as indicated by several authors [9,10] is that consumers' purchasing decisions are influenced by the end-of-life of the product rather than the environmental impacts in the production and transport phases.

With regard to on-premises markets, PET and steel kegs appear to be the most promising competitors to glass. Both contain more volume for the same weight, and steel can be used multiple times, theoretically with endless use. In addition, the distribution phase is more critical for glass, due to the fragility of the material, which also has a major impact on secondary and tertiary packaging and on the type of materials used (pallets, films, and carton boxes) [11].

In recent years, the use of steel kegs for serving wine on tap has increased dramatically, especially in the United States, Australia, and New Zealand [12]. In Europe, the use of bottles is widespread, but innovative alternative packaging seems to be appreciated both by retailers, who want to reduce the costs generated by waste by enhancing the efficiency of resource management and distribution, and by consumers who are more and more interested in sustainable wine consumption [13].

Two methodologies deemed by academics as most suitable for assessing the environmental impacts and the economic aspects of agri-food products during their life cycle are the Life Cycle Assessment (LCA) and the Life Cycle Costing (LCC).

Recent studies have investigated the environmental impacts of wine grape production [14], grape cultivation and wine making [15,16]. Other works have considered the life cycle of a wine bottle [17] and the environmental impacts of consumption [18]. Cultivation [19–21] and the wine-making process [22,23] have also been studied from an economic point of view.

In recent literature, studies can be found that relate PET and steel kegs for beer consumption [24,25], but only one paper assesses the environmental impact of PET keg adoption in the wine industry [26].

In light of the above, the research question is related to the environmental and economic competitiveness of different materials commonly used for packaging wine sold on local and international markets.

The objective of this study is to evaluate the environmental impacts and life cycle cost of three packaging systems (glass vs. PET vs. steel) of Campania's Falanghina PGI wine on tap, in three market scenarios, i.e. local, Italy vs. regional, Germany vs. international, USA. Alternative scenarios are defined considering the variation of the three packaging systems and the distance of distribution on the market in order to identify the aspects that most influence the environmental and economic performances of wine on tap.

The case study is an Italian winery (located in the Campania region), which processes 7,300 hl of wine, mostly marketed in 20 l stainless steel keg containers, in 0.75 l glass bottles and in 20 l disposable PET keg recipients.

The wine portfolio consists of 22 references, two of which are light sparkling wines that account for more than 30% of all wines in terms of volume. Among still wines, Campania Falanghina PGI (obtained by an autochthonous/local cultivar) represents the largest in terms of volume share and annual growth rate.

The hypothesis is that large packaging that can be reused several times is less impactful from an environmental and economic viewpoint than packaging used only once.

2. METHODOLOGY

2.1. Functional Unit and system boundaries

The volume of the beverage is typically chosen as the functional unit (FU) for LCA and LCC analyses and, in particular, other studies that have focused on wine have defined their FU as 0.75 l or 1 l of wine [27,28]. When analysing the consumption of wine on the premises, we

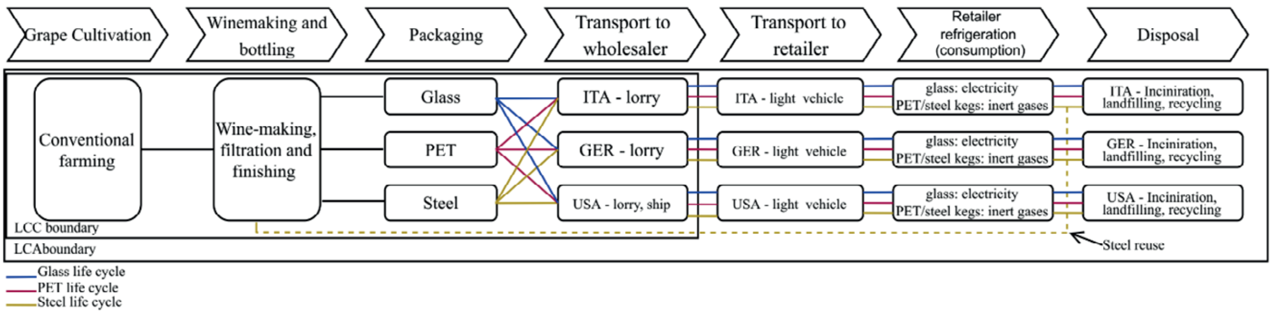

Figure 1. System boundaries.

chose a 125 ml glass as FU, because that allowed us to compare Falanghina PGI wine marketed in different volume packages.

We considered the on-trade markets to carry out a cradle-to-grave environmental analysis, while the economic analysis was conducted from cradle to wholesale. Cultivation of grapevine, winemaking, packaging, transport, refrigeration and waste management were considered and the allocation method by mass was used, considering that the wine yield of a unit mass of grapes is about 70%.

The decision to adopt two systems lies in the fact that there are limitations when estimating both the transport costs from the wholesaler to the retailer and the product handling phase at the point of sale: the wine storage and service phase by the retailer could not be calculated because of the high variability due to the intrinsic characteristics of the shops, which results in very different costs (Figure 1).

2.2. LCA methodology

2.2.1. Inventory analysis and impact assessment

The software tool SimaPro 8.5 (PRE Consultants, Amersfoort, The Netherlands) was used to perform the LCA.

For vine growing, winemaking, packaging and transport, we obtained primary data from the winery; for refrigeration and disposal, we used background data from the Ecoinvent v.3.7 database.

The environmental impacts of the three packaging techniques and the three markets were calculated by adopting the IMPACT 2002+ method.

2.2.2. Grape cultivation

Grape cultivation was analysed from cradle to farm gate. We assumed that Falanghina PGI grapes are grown with a conventional farming model. All input was provided by the farmers, and we processed it considering the production cycle in the following phases: fertilisation, fungicide treatments, pesticide treatments, pruning, inter-row management, irrigation, and harvesting.

It was assumed that the vineyard is in full production, and vineyard establishment and end-of-life were excluded from the assessment as these stages represent minor impacts due to the long (and uncertain) lifespan of the vineyard.

Table 1 shows data for agricultural operations.

2.2.3. Winemaking

The vinification phase considers two steps:

Step 1 – Winemaking with all related operations (Table 2)

Step 2 – Filtration and finishing with addition of pre-packaging products (Table 3)

Table 1. Inventory data for vineyard (amount per 125 ml of wine).

	Unit	Amount
Input from nature		
Water	m^3	1.49E-02
Input from the technosphere		
Diesel	kg	4.06E-03
Lubricating oil	kg	8.78E-05
Urea, as N	kg	5.00E-04
Ammonia	kg	3.33E-04
Phosphate fertiliser	kg	4.17E-04
Potassium fertiliser	kg	4.17E-04
Sulphur trioxide	kg	6.25E-04
Dithiocarbamate-compound	kg	9.52E-05
Copper oxide	kg	1.49E-04
Sulphur	kg	2.34E-04
Poles, softwood, PCP treated	m^3	1.98E-04
Aluminium around bimetallic steel wire	m	8.93E-03

Table 2. Amount of all input in the first wine-making step (per 125 ml of wine).

Input	Unit	Destemming and crushing	Fermentation	Racking	Clarification	Cleaning	Cooling
Energy	kWh	3.50E-04		2.50E-05			1.33E-02
Yeasts	G		2.50E-02				
Potassium metabisulphite	g		6.25E-03				
Fermentation activator	g		5.00E-02				
Enzymes	g		1.25E-03				
Bentonite	g				6.25E-02		
Detergents	g					7.00E-02	

Table 3. Amount of all input in the second wine-making step (per 125 ml of wine).

Inputs	Unit	Amount
Water	$g\ l^{-1}$	2.70E-03
Electricity	$kWh\ l^{-1}$	3.75E-04
Potassium metabisulphite	$g\ l^{-1}$	6.25E-03
Colloids	$g\ l^{-1}$	1.88E-02
Tanning	$g\ l^{-1}$	1.25E-03
Lightener	$kWh\ l^{-1}$	1.75E-03

Table 4. Input in glass bottle packaging (per 125 ml of wine).

Input	Unit	Amount
Glass bottle	g	75
Cork closure	g	6.88E-01
Capsules	g	1.33E-01
Label	g	1.40E-01
Electricity	kWh	4.00E-03
Water	g	2.00E-02
Nitrogen	g	1.00E-01
Cardboard	g	6.34

2.2.4. Packaging

Three different wine packaging systems were considered: 0.75 l glass bottle, 20 l PET keg and 20 l steel keg.

Both the glass bottle and the PET keg are one way, while the steel keg is recyclable; therefore, the amount of steel per FU depends on the reference market scenario (Italy, Germany, or USA) and on the lifetime of the kegs. The winery declared that the life cycle of steel kegs lasts about 10 years and the number of roundtrips depends on the destination: 9 roundtrips/year for the Italian scenario, 5 roundtrips/year for the German scenario, and 2 roundtrips/year for the US scenario.

Considering the weight of the 20 l steel keg (6.4 kg, or 40 g FU^{-1}), its lifespan and the number of roundtrips, the right amount of steel FU^{-1} for each scenario is the following:

- 0.4 g steel FU^{-1} in the Italian scenario
- 0.8 g steel FU^{-1} in the German scenario
- 2.0 g steel FU^{-1} in the US scenario.

Tables 4, 5 and 6 show the input used for each type of packaging.

To calculate the amount of packaging film used to wrap pallets, the European standard pallet size (0.8 m x 1.2 m) with an average height of 1.8 m [29] were assumed.

Table 5. Input in PET keg packaging (per 125 ml of wine).

Inputs	Unit	Amount
PET	g	6.25E-01
Capsules	g	7.25E-02
Electricity	kWh	3.88E-04
Fuel	g	2.38E-03

Table 6. Input in steel keg packaging (per 125 ml of wine).

Inputs	Unit	Amount		
		ITA	GER	USA
Stainless steel	g	4.45E-01	8.00E-01	2.00
Capsules	g	7.25E-02	7.25E-02	7.25E-02
Electricity	kWh	3.13E-03	3.13E-03	3.13E-03
Water	g	1.25E-01	1.25E-01	1.25E-01
Nitrogen	g	1.25	1.25	1.25

2.2.5. Transport

The wine wholesalers are located in Verona (for the Italian scenario), Frankfurt (for the German scenario) and New York (for the US scenario) respectively, thus causing a different environmental impact due to both the distance and the vehicles used during transport. The estimation of vehicle emissions was carried out considering the average values of emissions from the use of Euro 4, Euro 5 and Euro 6 lorries [29], light commercial vehicles and, for the US scenario only, transoceanic ships.

- Italian and German scenarios: The distance between the winery and the wholesaler is 700 km for the Italian scenario and 1,450 km for the German scenario; a lorry (32 tonnes) was considered for the transport. The average distance from the wholesaler to the retailers was assumed at 150 km for both scenarios, considering a light commercial vehicle.
- US scenario: For overland transport from the winery's headquarters to the port of Livorno (Italy), 550 km were assumed with a 32-tonne truck. For transport from Italy to the wholesaler located in the port of New York, a transoceanic ship with cooling was considered. From the wholesaler to the retailer, a light commercial vehicle was considered, for an average distance from wholesaler to retailer of 50 km.

2.2.6. Retailer refrigeration

During the refrigeration phase, the electricity consumption for the glass bottle scenario was assumed to be 1.025E-03 kWh FU^{-1} in 12 hours of refrigeration (average time assumed before wine tapping). For the PET keg and steel keg scenarios, the use of electricity is limited to the tapping phase (Table 7) and the refrigeration is managed using inert gases, leading to a refrigerant loss, which was also considered. The leakage of R404A and its three components for FU are shown in Table 7; as also reported by Amienyo and Azapagic [24], the Global Warming Power of R404A was estimated in 3.860 kg CO2 eq. kg^{-1}.

2.2.7. Packaging end of life (waste management)

The end-of-life phase of packaging systems was modelled by considering disposal scenarios consisting of incineration, landfilling, and recycling processes. PET keg and glass bottle are one way, while the steel keg is used for 10 years, then replaced at the end of the life cycle. Regarding the percentages of these processes, official data from each scenario was assumed: ISPRA for Italy [30]; the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety for Germany [31], and United States Environmental Protection Agency for the USA [32].

2.2.8. Scenario modelling

A key option for reducing the environmental impact of wine consumption is closely related to the weight of packaging. In defining the alternative scenario, the potential reduction in life cycle environmental impact was analysed by considering alternative packaging containers with a weight reduction of 33% per glass bottle, PET keg and steel keg.

2.3 LCC methodology

Life cycle costs were evaluated according to [24,33] the methodological approach given in Hunkeler [34]

Table 7. Leakage of refrigerant R404A and its component (amount per 125 ml of wine).

Refrigeration leakage	GWP	R404A losses	1,1,1 – Trifluoroethane	Pentafluoroethane	1,1,1,2 – Tetrafluoroethane
PET keg	2.90	7.50E-04	3.90E-04	3.30E-04	3.00E-05
Steel keg	2.90	7.50E-04	3.90E-04	3.30E-04	3.00E-05

Table 8. Waste management scenarios.

Disposal scenario	Glass			PET			Steel		
	Italy	Germany	USA	Italy	Germany	USA	Italy	Germany	USA
Recycling	74%	85%	31%	44%	93%	14%	78%	91%	74%
Landfilling	26%	9%	55%	13%		69%	22%	9%	21%
Incineration		6%	13%	43%	7%	17%			5%

and Swarr [35] concerning the Conventional LCC calculation.

The following equation (Eq. 1) includes the phases and material useful to calculate the LCC of 125 ml of wine from field to wholesaler.

$$LCCw = Cc + Cp + Cwpb + Ct \qquad (1)$$

Where:
LCCw wine life cycle costs of 125 ml of wine
Cc costs of vine cultivation
Cp costs of packaging (glass bottle or PET keg or steel keg)
Cwpb costs of wine production and bottling
Ct costs of transport to wholesaler (Italy, Germany or United States)

All cost items are given per functional unit and reported in the unit of measure € $125ml^{-1}$.

All costs for cultivation, packaging, wine production and bottling were collected directly from the case study company. The LCC was conducted following an activity-based costing approach. In addition, different cost separation criteria and cost centres were taken into account in order to elaborate the balance sheet data set.

Table 9. Categories of direct and indirect costs.

Category	Type of cost	Description
A_1	Direct	Raw materials (Wine)
B_1	Direct	Oenological products
B_2	Direct	Water
B_3	Direct	Detergents
B_4	Direct	Plant electricity consumption
B_5	Direct	Cooling system electricity consumption
B_6	Direct	Inert gas
B_7	Direct	Eno-registers consulting fee
B_8	Direct	Estimates for losses of product
B_9	Direct	Depreciation
B_{10}	Direct	Lab analysis
B_{11}	Direct	Microfiltration membranes
B_{12}	Direct	Rectified grape must concentrate
C_1	Direct	Packaging materials
D_1	Indirect	Production labour
D_2	Indirect	Production equipment depreciation
E_1	Indirect	Leased assets
E_2	Indirect	Consumables
E_3	Indirect	Logistical
E_4	Indirect	General
E_5	Indirect	Bank charges
E_6	Indirect	Personnel
E_7	Indirect	Depreciation

In analytical cost accounting, the most commonly used categories are *direct* and *indirect* costs [36]. Therefore, the primary criterion for separating costs is based on the distinction between:

- Direct Costs, which are allocated directly to cost objects, based on an objective measurement of the input consumed by the cost object;
- Indirect Costs, which are allocated or charged indirectly to the cost object because the amount of the input consumed by the cost object in question has not been objectively measured.

The above categories have been broadly divided (as shown in Table 9) into direct and indirect costs.

Category A includes direct costs for raw materials; category B (B1, B2, …, Bn) includes direct costs of different types; while category C is the direct cost for packaging. Category D indicates indirect costs and considers labour costs for packaging (D1) and depreciable assets (D2); finally, category E includes general indirect cost centres (E1, … Em).

The transport phase for the three scenarios is external to the company and was calculated through the analysis of contracts with transport companies.

3. RESULTS AND DISCUSSION

As shown in Figure 2 and 3, the resource (expressed in MJ of primary energy) and climate change (kg CO2 eq.) indicators in the three scenarios were compared to assess the environmental impact of glass bottle, PET keg and steel keg packaging for the selected FU.

For both indicators, the total environmental impact of each type of packaging is given by the sum of the following phases:

- Cultivation
- Winemaking
- Packaging
- Transport to the wholesaler
- Transport to the retailer
- Refrigeration
- Waste management

As the cultivation and winemaking techniques are the same regardless of the type of packaging, their environmental impact is equal for each scenario. In terms of resources used, the sum of their values is the highest of all the phases considered (2.3 MJ primary energy FU^{-1}), while in terms of GWP they barely reach 0.06 kg CO2 eq. FU^{-1}.

In terms of resource consumption, the vineyard cultivation and winemaking phases remain among the most impactful; however, in the case of scenarios involving the use of glass bottle packaging, the latter becomes relevant in defining the overall impact.

The production steps that lead to a greater difference between the three scenarios considered are packaging and transport for two reasons: 1) the amount and type of raw material used in packaging and 2) the distance between cellar and retailer. The glass bottle is the most impactful packaging, followed by the PET keg and the steel keg; the higher quantity of raw material used for the glass bottles and the total weight of each batch led to a greater environmental impact.

Regarding the impact of transport, it is obviously linked to distance: the greater the distance, the higher the environmental impact. Therefore, the "US scenario" has the highest values, followed by the "German scenario" and the "Italian scenario".

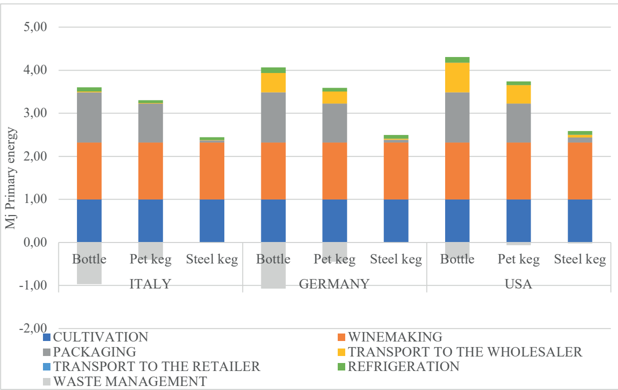

Figure 2. Resources: environmental impact of glass bottle, PET keg and steel keg in the three scenarios considered (Italy, Germany and USA).

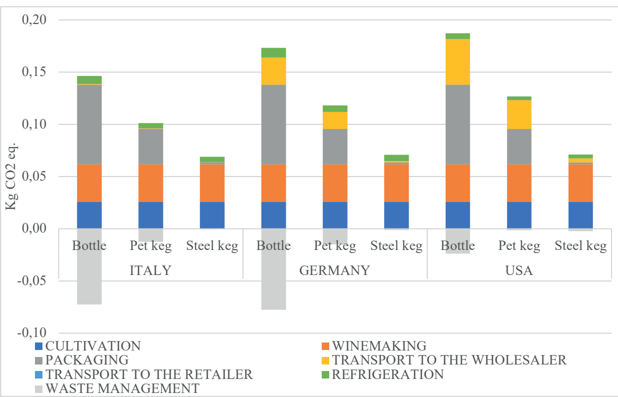

Figure 3. Climate change: environmental impact of glass bottle, PET keg and steel keg in the three scenarios considered (Italy, Germany and USA).

Also considering waste management, glass bottles can become competitive again in Italy and Germany, thanks to the high level of recycling of this material and the low percentage of landfill disposal.

Table 10 shows the results of the scenario analysis, highlighting the different impact of packaging weight reduction in the market scenarios investigated. A significant change emerges with the use of the glass bottle as the primary packaging container. In this case, the Climate Change indicator shows a reduction in impact of as much as 1/3 for the commercial scenario on a domestic scale, clearly evidencing the impact of this type of container on the product life cycle. Less sharp results were obtained on a regional and international scale, but again there is evidence that a significant share of the overall impact is attributable to the container. For the PET keg container, the reduction results, although appreciable, are more limited, also considering the large volume transported per single unit. The use of the steel keg shows no significant difference, considering the re-use of the container for several trips. These results also express the relationship between packaging weight and distance travelled to market, highlighting the strong environmental impact of packaging for short-marketed products.

The cost analysis shows the high competitiveness of the steel keg format compared to the PET keg and the glass bottle, due to the possibility to reuse the packaging and thus spread the purchase costs over many trips. The least competitive scenario is where the glass bottle is used, mainly because of the cost of buying glass. Considering the costs incurred by the winery to deliver the wine in the three scenarios (Table 11), it can be seen that, on the domestic market, the most competitive format is the steel keg; for the European destination, the choice of one of the two keg formats analysed does not influence the total cost. For the US scenario, the most competitive format is the steel keg (-3.4% compared to PET).

Looking at individual cost items, raw material (wine), category A is the item that alone accounts for most of the costs in the PET and steel keg scenarios, while for the glass bottle, category B represents the highest costs.

The packaging (category C) in steel keg accounts for 0.3% of production costs; this value rises to 3.5% for PET keg and 4.1% for the glass bottle.

Going into greater detail, the wine production and bottling phase (categories B and D) differ in the use of the three types of packaging, due to manual labour in the bottling phase and in all the phases prior to bottling, such as the cleaning of each container, the management of the bottling line, and the subsequent activities of warehouse logistics. In particular, category B is

Table 10. Scenario modelling results (33% of weight reduction for packaging).

	Glass			PET			Steel		
	Italy	Germany	USA	Italy	Germany	USA	Italy	Germany	USA
Resources	-13%	-12%	-10%	-7%	-7%	-6%	-2%	-1%	-1%
Climate change	-30%	-26%	-15%	-8%	-7%	-6%	0%	0%	0%

Table 11. Cost analysis results (€ FU^{-1}).

Format	Production cost categories					Transport scenario			Total costs scenario		
	Cultivation	Wine production and bottling				IT	GE	US	IT	GE	US
	A	B	C	D	E						
Glass bottle	0.1150	0.1221	0.0116	0.0100	0.0263	0.0163	0.0350	0.0383	0.3013	0.3200	0.3233
PET	0.1150	0.0394	0.0069	0.0113	0.0263	0.0113	0.0250	0.0276	0.2100	0.2238	0.2264
Steel keg	0.1150	0.0132	0.0005	0.0163	0.0263	0.0225	0.0525	0.0475	0.1938	0.2238	0.2188

higher for the glass bottle because of the higher energy consumption of the various machines that constitute the line, compared to the keg plant and the high incidence of the fixed costs of the plant. Conversely, category D is higher for kegs because the incidence of the cost of personnel employed in the various operations is higher than for other production lines.

Turning to transport costs, carriers define unit costs that depend on the kilometres travelled and the type of material. PET packaging is the cheapest on all routes because it is the lightest in terms of volume transported. Glass remains competitive on the domestic market, but not on the European and US markets. For steel packaging, the return of the empty container is also considered in the costs shown.

Packaging in the food industry has to consider various environmental and economic requirements in addition to marketing, logistics, and production. As another study [37] points out, there are two central elements to focus on when choosing the right packaging: the packaging material and the packaging end-of-life. The packaging sector evolved initially because of the need to produce new materials for technological reasons related to wine transport and preservation. Currently, the need to find effective ways to reduce costs and environmental impact have led to new design paradigms [38].

This study shows that wine steel and PET have comparable and significantly better economic performance than glass packaging, with steel achieving the best environmental results. Similar considerations were expressed by Brock and Williams [39] who found that glass and the recycled glass bottle are still the most impactful packaging. Another study confirms the findings of this work for beer [40], with glass containers appearing to be the most expensive compared to steel. Reusable packaging systems therefore appear to be more competitive in the supply chain than single-use packaging, as also demonstrated by Mahmoudi and Parviziomran [41].

In these terms, it is difficult to find alternative solutions considering on the one hand the tradition of using the glass bottle container and, on the other hand, the perception of the consumer.

Not all studies agree on the importance of wine packaging, but it seems that bottle design may play an important role in some old-world markets that are more tied to tradition [42], but also in relation to more innovative products, as for fruit wines that highlight the fundamental role of packaging in defining the attractiveness of the product [43]. A recent study [44], indicates that Portuguese consumers associate the heavier glass bottle with better quality and a higher price, while at the same time expressing concerns about the presence of plastic in the packaging that may reduce recyclability and reuse.

This condition is less evident for tap wine, but the cultural link with tradition can potentially influence the choice. Nevertheless, the role of the consumer has been changing in recent years, and more and more attention is being paid to environmental claims and to the communication of the role of limiting impacts by wineries [45], which now consider their carbon neutrality and containment process as development objectives in the medium and long term.

Moreover, in the last few years, experiments are being conducted to evaluate alternative packaging such as bioplastic bottles, which would guarantee a reduced environmental footprint but would be more expensive [46,47]. Compared to our case study, the use of PET kegs seems to be interesting from an economic point of view; however, from a circular economy perspective and considering the increasing awareness of consumers on the use of recyclable and reusable products compared to the classical disposable ones, it seems inevitable for companies operating in the beverage sector to adopt green strategies [48].

In addition, when considering wine packaging, one must actually refer to three levels of packaging: primary packaging, which includes the container intended for the end consumer and with the function of protecting and advertising the product; secondary packaging, used to group bottles, for example in cardboard boxes; tertiary packaging, such as containers used to combine groups of packages into larger loads for transport [49]. The discourse, therefore, becomes broader and refers to many materials, paper, cardboard, plastic, and wood *in primis*. These materials are also chosen by the industry according to the form of distribution.

The transport of wine has emerged as one of the main causes of environmental impact both because of direct emissions, mainly due to fuel consumption during logistics and product handling, but also indirectly because it determines the choice of packaging materials, especially secondary and tertiary packaging, and therefore requires more effective solutions. Other studies also confirm the results of this research and emphasise the need to analyse the role of packaging in the agro-food system from a holistic point of view considering its interaction with the logistics phase [50].

Finally, focusing on the end-of-life results obtained by the different packaging systems, the glass bottle generated the greatest environmental benefits, due to its efficient waste management system, mainly based on recycling. However, its impact is greater than the other two systems, as reuse, in the case of steel keg, seems to be a strong point for sustainability, as confirmed by other authors [51]. In order to limit environmental impacts and costs, new packaging, such as bag-in-box and Tetra Pak with integrated use of cardboard or paperboard layers, has entered the wine market in recent years, with the dual aim of maximising the volume transported and containing costs, while at the same time reducing environmental impact at the end of life. However, even these products are only partially recyclable [52].

3. CONCLUSIONS

This study lays the basis to support wineries, merchants, and retailers in their choice of wine packaging, taking into account the different target markets.

This is the first study in the wine sector to consider the entire product life cycle, by assessing both the dynamics and environmental impacts and costs with reference to all phases of the life cycle (production, transformation, distribution, consumption, and end of life). In this way, it has been possible to respond to a need of the industrial and logistics worlds that until now were not in a position to highlight the cost and environmental impact hot spots of the various phases that characterise wine consumption. We have been able to confirm that the glass bottle is still the most popular and appreciated packaging among consumers, probably for sentimental reasons and links with tradition. However, this container has obvious limits from the point of view of the circular economy, considering the limited volume transported for the same weight of the container, compared to other alternatives available on the market today.

Considering the above, companies are studying the possibility of using alternative packaging on the on-premise market, given that the use of glass bottles requires skilled employees, high cost technology, large space for storage and bottling equipment such as additional pack accessories: cork, screwcap, or cardboard. In addition, as the scenario analysis also showed, the traditional packaging consisting of the glass bottle makes a strong environmental contribution to the entire life cycle of the wine.

In this respect, PET kegs prove to be particularly competitive, especially because of their limited weight and considering that each keg carries the equivalent of more than 26 glass bottles; moreover, wineries do not have to consider backhaul and handling charges and there is no need to store empty containers. In addition to the obvious advantages for logistics and limited costs, the one-way use of this container, coupled with not always guaranteed recyclability, introduces doubts about its use from an environmental point of view.

The steel keg has interesting technological features, theoretically no end-of-life (unlimited use), and cleaning, filling, and packaging technologies that are much easier to handle than the bottle crate, and which are much less expensive. Furthermore, this container has a high material performance in terms of wine shelf life and is also suitable for sparkling wines.

On the other hand, this packaging has return transport costs, administration (book-keeping) and handling costs for the management of a keg, initial investment costs for the keg, and repair costs (higher for long routes or constant circulation rate). Therefore, companies need a surplus of containers throughout the year to manage seasonal fluctuations. Moving empty kegs over long routes increases the environmental impact and transport costs, and the process of washing and sanitising kegs before each use wastes water, energy, and chemicals.

Reusable packaging systems appear to be a viable alternative to replace single-use packaging in supply chain systems. The decision-making processes of companies should therefore include an analysis of the feasibility of using reusable packaging systems considering environmental and economic factors.

The future of research could lie in new forms of packaging eco-design, using materials with low environmental impact throughout the life cycle, aimed at improving container management in the logistics system. Therefore, with a view to optimising the whole chain, both environmental and economic factors should be considered organically through optimisation models applicable at cellar level. Furthermore, for future studies, it will be useful to consider case studies related to larger volume production, as the case examined refers to a production example of a medium-high range, low-volume wine. Likewise, the research should also investigate other markets, including emerging ones.

Another aspect concerns the consumer's approach to wine from different containers, which often favours glass. Consumer behaviour could be directed towards less impactful packaging with appropriate information campaigns both on the quality aspects of wine – which does not vary in containers made of different materials – and on the social commitment to reduce the impact of wine on the climate.

Finally, a central role could be played by institutions at various levels, both central and local, which could promote market-based schemes to reduce emissions based on taxes on environmental externalities, to internalise society's costs for the use of impactful packaging, and to translate environmental impacts into economic form.

REFERENCES

[1] Maicas, S.; Mateo, J.J. Sustainability of wine production. *Sustain.* **2020**, *12*.

[2] Flores, S.S. What is sustainability in the wine world? A cross-country analysis of wine sustainability frameworks. *J. Clean. Prod.* **2018**, *172*, 2301–2312.

[3] Deroover, K.; Siegrist, M.; Brain, K.; McIntyre, J.; Bucher, T. A scoping review on consumer behaviour related to wine and health. *Trends Food Sci. Technol.* **2021**, *112*, 559–580.

[4] Strub, L.; Kurth, A.; Loose, S.M. Effects of viticultural mechanization on working time requirements and production costs. *Am. J. Enol. Vitic.* **2021**, *72*, 46–55.

[5] Sellers-Rubio, R. Evaluating the economic performance of Spanish wineries. *Int. J. Wine Bus. Res.* **2010**, *22*, 73–84.

[6] Migliaccio, G.; Tucci, L. Economic assets and financial performance of Italian wine companies. *Int. J. Wine Bus. Res.* **2020**, *32*, 325–352.

[7] Nesselhauf, L.; Deker, J.S.; Fleuchaus, R. Information and involvement: the influence on the acceptance of innovative wine packaging. *Int. J. Wine Bus. Res.* **2017**, *29*, 285–298.

[8] Schwarz, A.E.; Ligthart, T.N.; Boukris, E.; van Harmelen, T. Sources, transport, and accumulation of different types of plastic litter in aquatic environments: A review study. *Mar. Pollut. Bull.* **2019**, *143*, 92–100.

[9] Boesen, S.; Bey, N.; Niero, M. Environmental sustainability of liquid food packaging: Is there a gap between Danish consumers' perception and learnings from life cycle assessment? *J. Clean. Prod.* **2019**, *210*, 1193–1206.

[10] Brennan, L.; Langley, S.; Verghese, K.; Lockrey, S.; Ryder, M.; Francis, C.; Phan-Le, N.T.; Hill, A. The role of packaging in fighting food waste: A systematised review of consumer perceptions of packaging. *J. Clean. Prod.* **2021**, *281*.

[11] Molina-Besch, K.; Wikström, F.; Williams, H. The environmental impact of packaging in food supply chains—does life cycle assessment of food provide the full picture? *Int. J. Life Cycle Assess.* **2019**, *24*, 37–50.

[12] Nuebling, M.; Behnke, C. Wine on tap: Wine consumers', restaurants', and wineries' perspectives of wine on tap. *Wine Vitic. J.* **2017**, *32*, 68–71.

[13] Pougnet, S.; Martin-Rios, C. Keg wine as a sustainability-oriented innovation. *Proc. XXX ISPIM Innov. Conf.* **2019**, 12 p.

[14] Russo, V.; Strever, A.E.; Ponstein, H.J. Exploring sustainability potentials in vineyards through LCA? Evidence from farming practices in South Africa. *Int. J. Life Cycle Assess.* **2021**.

[15] Harb, W.; Zaydan, R.; Vieira, M. Improving environmental performance in wine production by life cycle assessment: case of Lebanese wine. *Int. J. Life Cycle Assess.* **2021**.

[16] Laca, A.; Gancedo, S.; Laca, A.; Díaz, M. Assessment of the environmental impacts associated with vineyards and winemaking. A case study in mountain areas. *Environ. Sci. Pollut. Res.* **2021**, *28*, 1204–1223.

[17] Bonamente, E.; Scrucca, F.; Rinaldi, S.; Merico, M.C.; Asdrubali, F.; Lamastra, L. Environmental

impact of an Italian wine bottle: Carbon and water footprint assessment. *Sci. Total Environ.* **2016**, *560–561*, 274–283.
[18] Amienyo, D.; Camilleri, C.; Azapagic, A. Environmental impacts of consumption of Australian red wine in the UK. *J. Clean. Prod.* **2014**, *72*, 110–119.
[19] Taylor, A.S.; Cook, D.C. An economic assessment of the impact on the Western Australian viticulture industry from the incursion of grapevine downy mildew. *J. Plant Dis. Prot.* **2018**, *125*, 397–403.
[20] Aparicio, J.; Tenza-Abril, A.J.; Borg, M.; Galea, J.; Candela, L. Agricultural irrigation of vine crops from desalinated and brackish groundwater under an economic perspective. A case study in Siġġiewi, Malta. *Sci. Total Environ.* **2019**, *650*, 734–740.
[21] Falcone, G.; Strano, A.; Stillitano, T.; De Luca, A.I.; Iofrida, N.; Gulisano, G. Integrated sustainability appraisal of wine-growing management systems through LCA and LCC Methodologies. *Chem. Eng. Trans.* **2015**, *44*, 223–228.
[22] Zhang, C.; Rosentrater, K.A. Estimating economic and environmental impacts of red-wine-making processes in the USA. *Fermentation* **2019**, *5*.
[23] García-Alcaraz, J.L.; Flor Montalvo, F.J.; Martínez Cámara, E.; Pérez de la Parte, M.M.; Jiménez-Macías, E.; Blanco-Fernández, J. Economic-environmental impact analysis of alternative systems for red wine ageing in re-used barrels. *J. Clean. Prod.* **2020**, *244*.
[24] Amienyo, D.; Azapagic, A. Life cycle environmental impacts and costs of beer production and consumption in the UK. *Int. J. Life Cycle Assess.* **2016**, *21*, 492–509.
[25] Cimini, A.; Moresi, M. Carbon footprint of a pale lager packed in different formats: Assessment and sensitivity analysis based on transparent data. *J. Clean. Prod.* **2016**, *112*, 4196–4213.
[26] Ferrara, C.; Zigarelli, V.; De Feo, G. Attitudes of a sample of consumers towards more sustainable wine packaging alternatives. *J. Clean. Prod.* **2020**, *271*.
[27] Cleary, J. Life cycle assessments of wine and spirit packaging at the product and the municipal scale: A Toronto, Canada case study. *J. Clean. Prod.* **2013**, *44*, 143–151.
[28] Ponstein, H.J.; Ghinoi, S.; Steiner, B. How to increase sustainability in the Finnish wine supply chain? Insights from a country of origin based greenhouse gas emissions analysis. *J. Clean. Prod.* **2019**, *226*, 768–780.
[29] Ferrara, C.; De Feo, G. Comparative life cycle assessment of alternative systems for wine packaging in Italy. *J. Clean. Prod.* **2020**, *259*.
[30] ISPRA Municipal waste report, 331/2020.
[31] Federal Ministry for the Environment Nature Conservation and Nuclear Safety Waste Management in Germany 2018 – Facts, data, diagrams. *BMUV* **2018**, 44.
[32] United States Environmental Protection Agency (EPA) Containers and Packaging: Product-Specific Data.
[33] Verduna, T.; Blanc, S.; Merlino, V.M.; Cornale, P.; Battaglini, L.M. Sustainability of Four Dairy Farming Scenarios in an Alpine Environment: The Case Study of Toma di Lanzo Cheese. *Front. Vet. Sci.* **2020**, *7*.
[34] Hunkeler, D.; Lichtenvort, K.; Rebitzer, G. *Environmental life cycle costing*; Crc press, 2008; ISBN 1420054732.
[35] Swarr, T.E.; Hunkeler, D.; Klöpffer, W.; Pesonen, H.-L.; Ciroth, A.; Brent, A.C.; Pagan, R. Environmental life-cycle costing: A code of practice. *Int. J. Life Cycle Assess.* **2011**, *16*, 389–391.
[36] Blanc, S.; Massaglia, S.; Brun, F.; Peano, C.; Mosso, A.; Giuggioli, R.N. Use of Bio-Based Plastics in the Fruit Supply Chain: An Integrated Approach to Assess Environmental, Economic, and Social Sustainability. *Sustain.* 2019, *11*.
[37] Molina-Besch, K.; Pålsson, H. A simplified environmental evaluation tool for food packaging to support decision-making in packaging development. *Packag. Technol. Sci.* **2020**, *33*, 141–157.
[38] Escursell, S., Llorach-Massana, P., Roncero, M.B., Sustainability in e-commerce packaging: A review. *J Clean Prod* **2021**, 280
[39] Brock, A.; Williams, I. Life cycle assessment of beverage packaging. *Detritus* **2020**, *13*, 47–61.
[40] Wohner, B.; Gabriel, V.H.; Krenn, B.; Krauter, V.; Tacker, M. Environmental and economic assessment of food-packaging systems with a focus on food waste. Case study on tomato ketchup. *Sci. Total Environ.* **2020**, *738*.
[41] Mahmoudi, M.; Parviziomran, I. Reusable packaging in supply chains: A review of environmental and economic impacts, logistics system designs, and operations management. *Int. J. Prod. Econ.* **2020**, *228*.
[42] Chamorro, A., Garcia-Gallego, J.M., Trindade-Carlos, H.D., Study on the importance of wine bottle design on consumer choices. *British Food Journal* **2021**.123, 577–593.
[43] Merlino, V.M.; Fracassetti, D.; Di Canito, A.; Pizzi, S.; Borra, D.; Giuggioli, N.R.; Vigentini, I. Is the consumer ready for innovative fruit wines? Perception and acceptability of young consumers. *Foods* **2021**, *10*.

[44. Soares, J., Ramos, P., Pocas, F., Is lightweighting glass bottles for wine an option? Linking technical requirements and consumer attitude. *Packaging Technology And Science*, **2022**.35, 833–843.

[45] Capitello, R.; Agnoli, L.; Charters, S.; Begalli, D. Labelling environmental and terroir attributes: Young Italian consumers' wine preferences. *J. Clean. Prod.* **2021**, *304*.

[46] Aversa, C.; Barletta, M.; Gisario, A.; Pizzi, E.; Prati, R.; Vesco, S. Design, manufacturing and preliminary assessment of the suitability of bioplastic bottles for wine packaging. *Polym. Test.* **2021**, *100*.

[47] Merlino, V.M.; Brun, F.; Versino, A.; Blanc, S. Milk packaging innovation: Consumer perception and willingness to pay. *AIMS Agric. Food* **2020**, *5*, 307–326.

[48] Foschi, E.; Zanni, S.; Bonoli, A. Combining eco-design and LCA as decision-making process to prevent plastics in packaging application. *Sustain.* **2020**, *12*, 1–13.

[49] Palsson, H., Pettersson, F., Hiselius, L.W., Energy consumption in e-commerce versus conventional trade channels – Insights into packaging, the last mile, unsold products and product returns. *J Clean Prod* **2017**.164, 765–778.

[50] Garcia-Arca, J., Garrido, A., Prado-Prado, J.C., "Sustainable Packaging Logistics". The link between Sustainability and Competitiveness in Supply Chains. *Sustainability* **2017**,9.

[51] Simon, B.; Amor, M. Ben; Földényi, R. Life cycle impact assessment of beverage packaging systems: focus on the collection of post-consumer bottles. *J. Clean. Prod.* **2016**, *112*, 238–248.

[52] Thompson-Witrick, K.A.; Pitts, E.R.; Nemenyi, J.L.; Budner, D. The impact packaging type has on the flavor of wine. *Beverages* **2021**, *7*.