

# Life Cycle Assessment and Carbon Footprint in the Wine Supply-Chain

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**Abstract** Global warming represents one of the most critical internationally perceived environmental issues. The growing, and increasingly global, wine sector is one of the industries which is under increasing pressure to adopt approaches for environmental assessment and reporting of product-related greenhouse gas emissions. The International Organization for Vine and Wine has recently recognized the need to develop a standard and objective methodology and a related tool for calculating carbon footprint (CF). This study applied this tool to a wine previously analyzed using the life cycle assessment (LCA) methodology. The objective was to test the tool as regards both its potential and possible limitations, and thus to assess its suitability as a standard tool. Despite the tool's user-friendliness, a number of limitations were noted including the lack of accurate baseline data, a partial system boundary and the impossibility of dealing with the multi-functionality issue. When the CF and LCA results are compared in absolute terms, large discrepancies become obvious due to a number of different assumptions, as well as the modeling framework adopted. Nonetheless, in relative terms the results seem to be quite consistent. However, a critical limitation of the CF methodology was its focus on a single issue, which can lead to burden shifting. In conclusion, the study confirmed the need for both further improvement and adaptation to additional contexts and further studies to validate the use of this tool in different companies.

**Keywords** Wine industry · Carbon footprint (CF) · Life cycle assessment (LCA) · Vine

## Introduction

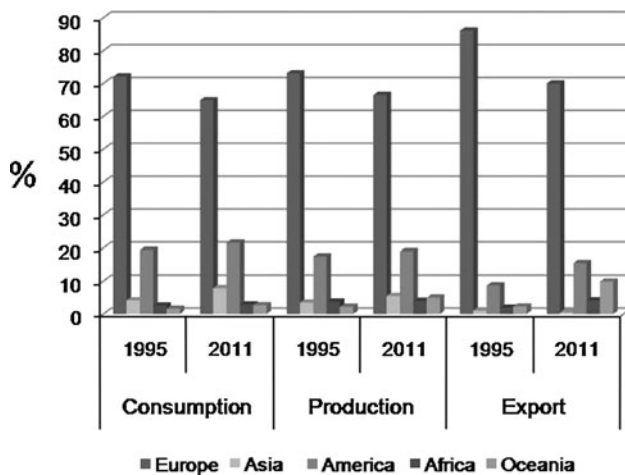
For many years the wine industry was dominated by European countries, but more recently it has become increasingly “global” due to the challenge from expanding wine industries in the Americas, Australia and Asia (especially China). Recently published data from the principal internationally recognized intergovernmental organization dealing with scientific and technical aspects of viticulture and winemaking, the International Organization of Vine and Wine (OIV), showed that in 2010 almost 8 million hectares were used worldwide for viticulture and the annual world production of wine was about 270 million hectoliters (OIV 2011). The increasing trend towards globalization in this industry is highlighted by the fact that over the last 15 years the European share of wine production worldwide has decreased from 73.1 % in 1995 to 66.5 % in 2010, to the benefit of all other world regions, which have seen an increase in their percentage shares (Fig. 1) (OIV 2011).

Worldwide wine consumption (Fig. 2) has shown an overall increase over the last 15 years, rising from a global consumption of 222 million hectoliters in 1996 to an estimated 238 million hectoliters in 2010, with the trend showing a recovery after the decrease recorded in 2008 and 2009, which was most likely due to the international crisis (OIV 2011). Moreover, the data show a redistribution of the percentage shares among the various world regions as regards consumption, similar to that described above for production (Fig. 1).

Even though wine is not a basic necessity, for some economies it is of significant importance in terms of export, and accounts for a large percentage of the GDP from the agro-industrial sector (Point 2008). After a continuous period of significant growth from 2000 onwards, global

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**Fig. 1** Percentage shares of the various world regions concerning production, consumption and exports of wine: 1995 versus 2011 (OIV 2011)

exports of wine were affected by the recent global economic crisis, and registered a slight decrease in 2009. However, in 2010 the trend recovered and the total volume of wine exported in 2010 (93.5 million hectoliters estimated) was 70 % higher than in 1995 (OIV 2011).

Against the background of a general increase in awareness of environmental issues related to agricultural activities (OECD 1998; Petti and others 2005; OECD 2008; Van der Werf and others 2007; Pathak and others 2010) and considering the amount of resources involved in the wine industry, there has been growing concern regarding environmental problems related to this industry, particularly in certain countries with a shorter tradition in wine-making (Australia, New Zealand, some American countries and South-Africa) (Benedetto 2010).

A common strategy is required for the sector to develop and evolve towards sustainable solutions for the economies of the different producer countries and for the ecosystems housing the cultivations.

In this context, a number of new wines have appeared on the market that claim to be environmentally sounder (Loureiro 2003). Organic wines, for instance, have

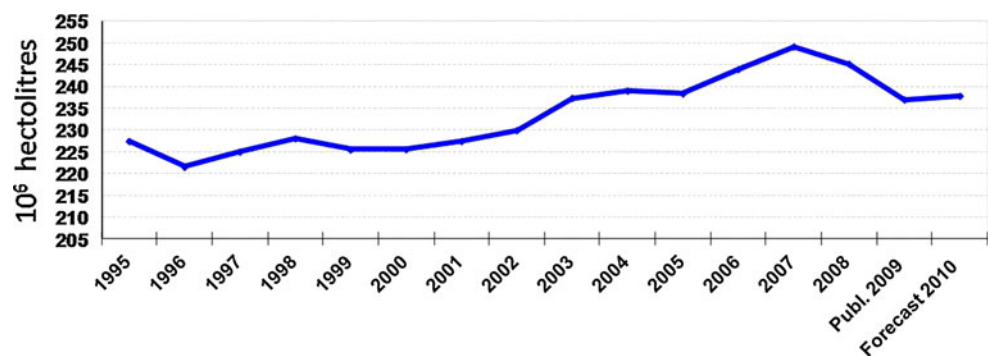
achieved rapid success in a similar way to the whole range of organically-grown food products. Indeed, for the last two decades, the organic wine sector has been growing continuously. In 2005, for example, the global organic wine market grew by 10 to 15 percent (Richter and Padel 2007; Willer 2008, Stolz and Schmid 2008).

However, whilst organic agriculture focuses on some inputs (e.g., pesticides and fertilizers) (EEC 1991), the increasing concern for a broader range of environmental issues has in fact imposed new development models based on innovative technologies that reduce the consumption of resources (energy, materials, chemicals) and the amount of pollutants and waste released, by maximizing the recovery and recycling of by-products throughout a product's life cycle.

In the case of the agri-food industry, and specifically in the viticulture and wine-making supply chain, various methodologies have been used to quantify and assess the environmental impacts throughout the product life cycle.

In this regard, the first methodology applied was Life Cycle Assessment (LCA), which is a standardized methodology (ISO 2006a; ISO 2006b) to assess the environmental burdens of a product, from its production to its disposal or recycling (cradle-to-grave approach). An increasing amount of studies have been published internationally, indeed, on LCA applied to the wine sector (Ardenne and others 2006; Benedetto 2010; CIV 2008a; b; Fearne and others 2009; Gazulla and others 2010; Morgante and others 2004; Petti and others 2006; Pizzigallo and others 2008). The wide scope of LCA, in terms of system boundaries and variety of impact categories considered, makes it a robust and holistic method for the analysis and quantification of the impacts of a product or process, which avoids the shift of environmental problems from one life-cycle step to another or from one impact category to another. On the other hand, its complexity means it is not very accessible for decision-making or communication purposes (Weidema and others 2008). This is especially true when the target group is not skilled as the assessment results are usually expressed as an environmental profile made of several specific indicators.

**Fig. 2** OIV data on worldwide wine consumption trend: 1995–2010 (OIV 2011)



A more recent adaptation to worldwide trends that focus on climate change issues, and therefore on the emission of CO<sub>2</sub> and other greenhouse gases (GHGs), has led to growing stress on the Carbon Footprint (CF) of products, especially in the statement of the impact of a given product in terms of global warming. This methodology involves the assessment from a life-cycle-oriented approach, of the global warming impact linked to the emissions of GHGs throughout a product's life cycle. In other words, the CF can be considered as a simplified LCA restricted to a single impact category, notably Global Warming (Weidema and others 2008). The timeliness of this theme is also evidenced by the growing number of scientific papers published in recent years on the CF issue (about 2,500 since 2000<sup>1</sup>).

Furthermore, subsequent to the issue of the Guidelines for Sustainable Viticulture (OIV 2004), the OIV is currently working on the final stages of the OIV-GreenHouse Gas Accounting Protocol (OIV-GHGAP) for the wine industry. This protocol aims to standardize a methodology for establishing the contribution of CO<sub>2</sub> emissions arising from wine production to minimize the comparability problems that would emerge if winemakers used different tools/assumptions to measure GHGs. The OIV-GHGAP is based on the International Wine Carbon Calculator Protocol (IWCCP) and the relevant Carbon Calculator (IWCC) (FIVS 2008) developed by an international consortium of winemakers' federations and formally endorsed by the International Federation of Wine and Spirits (FIVS 2008).

The aim of this work is to apply the Carbon Calculator v1.3. mentioned above to a previous LCA case-study in order to compare similarities between the impacts calculated (in quantitative terms under the heading GWP), to assess the user-friendliness of the software, and to see what the limitations of a CF approach might be compared to a traditional LCA. The objective was to provide information for decision-makers (OIV) on the possible use of this software as the official tool for calculating GHGs emissions linked to wine production.

## Carbon Footprint

As a result of growing interest in the climate change issue by Governments and consumers, who are increasingly aware of environmental issues, producers have been encouraged to adopt more environmentally-friendly solutions and to communicate them effectively to stakeholders

(Min and Galle 1997; Imkamp 2000; Chow and others 2003). In a recent survey carried out at the request of the Directorate-General for the Environment of the European Commission, in which over 26,500 randomly-selected EU citizens were interviewed, it emerged that “slightly more than 8 in 10 EU citizens felt that a product's impact on the environment is an important element when deciding which products to buy (34 % ‘very important’ and 49 % ‘rather important’); only 4 % said this is not important at all” (European Commission 2009). Moreover, almost half of the EU citizens interviewed said that ecolabeling plays an important role in their purchasing decisions. Finally, 72 % of the interviewees supported the introduction of a mandatory label indicating a product's carbon footprint (European Commission 2009).

Indeed, in recent years the CF and issues surrounding the greenhouse effect have attracted the interest of both the scientific community and the general public. As a result, a number of methodologies and tools have been developed and implemented to assess and communicate the CF (i.e., total amount of GHG emissions caused by a product, expressed in kg of CO<sub>2</sub>-equivalent) of single products. This phenomenon has been driven predominantly by large-scale distribution that was able to exploit its strong bargaining power to involve supplier companies. However, the bottom-up definition of this “standard”, that was created simultaneously in several countries and in many environments, resulted in a lack of uniformity in the rules and application conditions (Weidema and others 2008; Schöner and others 2011).

At present there are various methodologies and tools to evaluate the CF; these include the Greenhouse Gas Protocol (GHG Protocol) (Greenhouse Gas Protocol Initiative 2008; Forsyth and others 2008) developed by the World Resources Institute and the World Business Council for Sustainable Development, and the ISO 14064 standard (ISO 2006c) issued by the International Organization for Standardization. Both tools adopt a life-cycle-based approach to measure the emissions of GHGs (Waye 2008).

Moreover, in order to establish a uniform methodology for calculating the CF of products and services, the British Standards Institute, co-sponsored by the Carbon Trust—a non-profit company established in the UK to tackle climate change—and the UK Department for Environment, Food and Rural Affairs (DEFRA), developed the PAS 2050 specification to assess the amount of GHGs emitted throughout the life cycle of goods and services (BSI 2008). The main goal of this specification is to recognize the potential for organizations to use this method to deliver improved understanding of the GHG emissions arising from their supply chains, and to provide a common basis for the comparison and communication of results (BSI 2008). Furthermore, the Carbon Trust has

<sup>1</sup> From a search carried out in Scopus ([www.scopus.com](http://www.scopus.com)) on 31 January 2012 by using the following query: TITLE-ABS-KEY (“carbon footprint”) AND PUBYEAR > 1999, a total of 2,482 documents resulted

developed a carbon label that shows the contribution of each single product to the emissions of carbon dioxide. To support this initiative the Carbon Trust has also developed a tool to calculate the CF based on the guidelines of the PAS 2050 (Carbon Trust 2010).

Other international bodies, both public and private, are likewise creating platforms for the calculation of greenhouse gas emissions from single products or firms (Hild and others 2011).

The latest of these to appear is the draft version of the international standard ISO/DIS 14067 “CF of products — Requirement and guidelines for quantification and communication” (ISO 2012). This draft standard, which has been awaited for a number of months, makes explicit reference to ISO 14040 and ISO 14044 standards as the basis for the LCA methodology that should be applied for the quantification and assessment of the impacts deriving from greenhouse gas emissions. The limitations of considering only the greenhouse effect as the environmental impact examined is, however, recognized.

The ISO/DIS 14067 standard refers specifically to the comparison of two or more products as regards their environmental aspects when it clearly states, in ANNEX D, that this standard does not enable a judgment of the environmental superiority of one product over another. Moreover, it specifies that the only possible comparison would be one made by replicating each of the phases of the methodology’s implementation and using the same CF-PCR (Carbon Footprint - Product Category Rules).

As regards the communication issue the ISO/DIS 14067 envisages 5 types of communication (CF external communication report, CF performance tracking report, CF claim, CF label, CF declaration) for two possible targets (CF communication intended to be available to the public, CF communication not intended to be available to the public) and makes reference to the ISO 14020 series standards. In this same international context, but with a more specific reference to the wine sector, the OIV has chosen to develop their own protocol (OIV-GHGAP) and tool (GreenHouse Gas Accounting Calculator: GHGAC). These instruments, based on the IWCCP and the relevant IWCC (FIVS 2008) which were developed by an international consortium of winemakers’ federations and formally endorsed by the International Federation of Wine and Spirits (FIVS) ([www.fivs.org](http://www.fivs.org)), aim to assess wine companies and their products and fully analyze the various process stages in order to identify the GHG emissions and sequestrations caused by the production process and the whole supply-chain.

The OIV-GHGAP will consist of two elements: Enterprise Protocol (EP) and Product Protocol (PP).

The EP is designed primarily at an enterprise level for the international wine industry in compliance with current

international standards and practices for greenhouse gas accounting.

EP could be subdivided into 2 components:

- direct emissions: they will be studied on the basis of a business-to-business assessment to include the GHG emissions released up to, and including, the point where the input arrives at a new organization (including all upstream emissions);
- indirect emissions: they will be studied by considering the dependence of one enterprise on the activities of other enterprises.

The EP is intended to benefit organizations, businesses and other stakeholders in the wine sector by providing a clear and consistent method for the assessment of the GHG emissions associated to wine companies’ activities.

The PP will provide general guidance on the significant emissions associated with individual products in the wine sector. It will help define product level GHG emissions to the extent necessary to satisfy the expected international standards for life cycle analysis. PP is intended to be carried out as a business-to-consumer assessment, which includes the emissions arising from the full life cycle of the product. The PP is intended to benefit organizations, businesses and other stakeholders in the wine sector by providing a clear and consistent method for the assessment of the life cycle GHG emissions associated with wine as a product. The PP is designed to be used by the retailer agent to communicate information on the GHG emissions and removals associated to the life cycle of a product, i.e. its CF, to final consumers.

In this context, the protocol and calculator separate the emissions into three levels called Scope 1, Scope 2 and Scope 3, in order to simplify the consideration of both EP and PP. Scope 1 includes all the emissions which a company can control directly through ownership of the related activities (cultivation, wine-making, bottling). Scope 2 refers to purchased energy (heat or electricity). Scope 3 includes the emissions from all products/activities that are purchased from other companies. Scope 1 and 2 typically include the emissions involved when a firm develops plans to minimize impacts given that these scopes are considered to be the only ones directly controlled by the management. Scope 3 emissions represent a critical part of the viticulture and wine production supply-chain as it includes all goods and services purchased from other companies (e.g.: product packaging and transport).

According to the protocol, components that contribute less than 1 % to the total emissions (in CO<sub>2</sub>-eq) can be discarded from calculations; nevertheless, these emissions should be estimated and included in the emissions report if possible. Some emissions or sequestrations may be excluded when applying the rule, but they should be identified and justified with relevant data.



Welcome to the International Wine Carbon Calculator (IWCC) Start AB32 Accounting

In order to select the familiar units and region specific emission factors, please select a region from the coloured maps below. Start Carbon Footprint or Embodied Carbon Accounting

You have selected the following country and region: **South Africa** **South Africa** You have selected the following electrical grid: **South Africa**

### Units Used Within the Model

	Volume	Energy	Mass	Mileage	Gas Units	Distance	Crush	Power	Sugar	Land Area
Australia	L	GJ	kg	L/100km	scM	km	Tonnes	kWh	Brix	ha
New Zealand	L	GJ	kg	L/100km	scM	km	Tonnes	kWh	Brix	ha
United States	Gal (US)	Therm	lb	mpg	scf	mil	ton (short)	kWh	Brix	Acre
South Africa	L	GJ	kg	L/100km	scM	km	Tonnes	kWh	Brix	ha
United Kingdom	Gal (imp)	Btu	lb	L/100km	scf	mil	ton (long)	Therm	Brix	ha

**Fig. 3** Opening page (partial) of the International Wine Carbon Calculator, enabling choice of the geographical region and the automatic selection of the default familiar measurement units and further default assumptions (e.g., power mix, etc.)

Currently, carbon calculation does not include all elements of the short-term carbon cycle (e.g., CO<sub>2</sub> from wine fermentation, emissions from combustion or breakdown of vine prunings, etc.), or change in land use, infrastructure items and assets (barrels, tanks and machinery), business travel of employees, and most chemicals.

The Calculator used is available on-line at <http://www.wineinstitute.org/ghgprotocol> and contains 23 spreadsheets. The first page, the “Introduction” (Fig. 3), enables you to select the country for the winery to be analyzed. The familiar units of measurement are thus selected automatically, as well as the region-specific parameters and coefficients. A number of pages illustrate the calculator’s results with graphs, charts and tables (General summation, General summation Bar Chart, General Summation Pie Chart,) that sum up the figures calculated (one example is the screen display in Fig. 4).

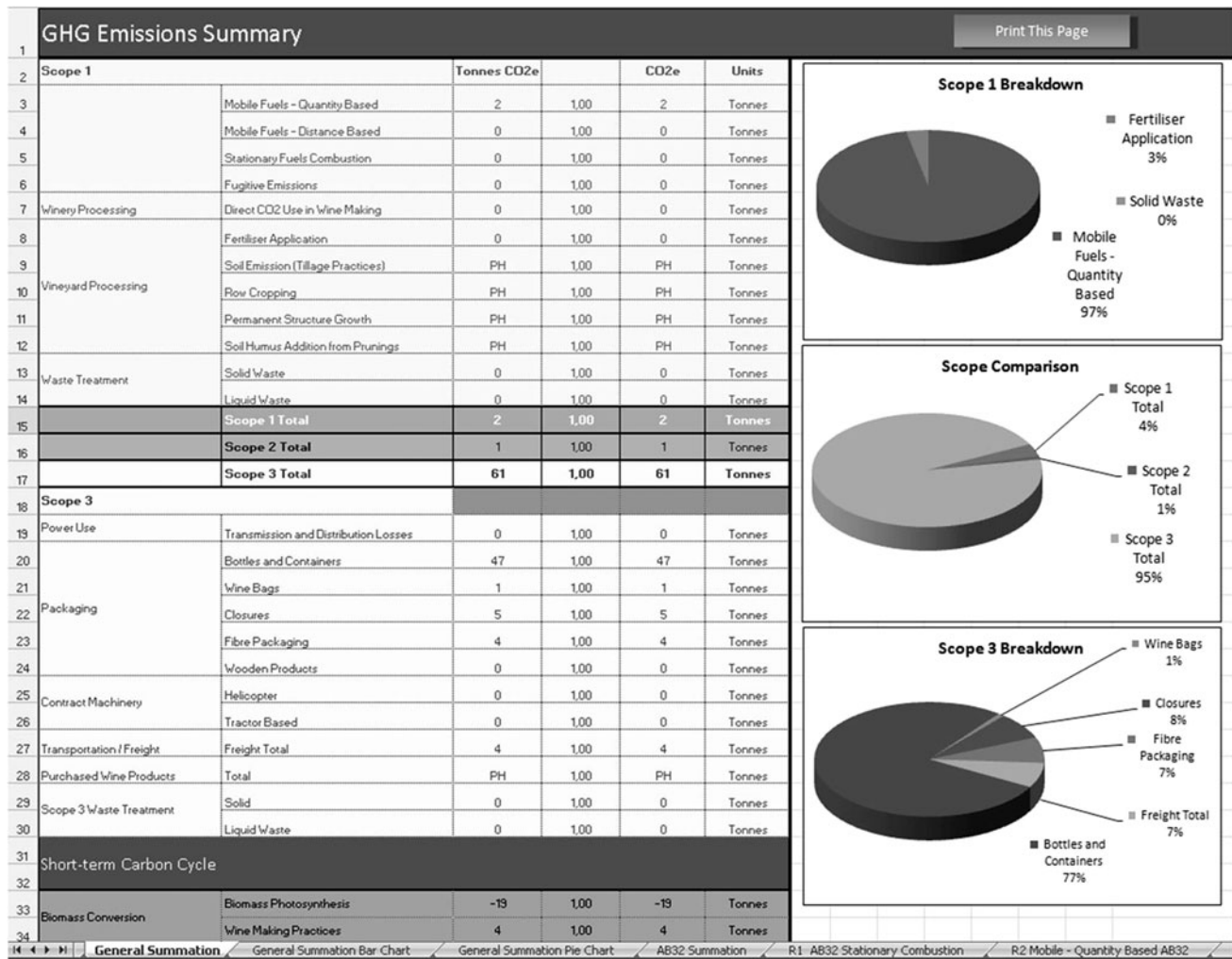
The software is easy to use, given that it is based on a well-known commercial spreadsheet. The data can be added in the relevant pages both simply and quickly, the only requirement being that data refer to summations (overall summation of the amounts used over the reference period).

### Case-Study Implementation

A preliminary implementation of the IWCC, version 1.3 (Wine Institute 2010), to an Italian wine product was made by using inventory data from a previous LCA study on an

organic wine produced by a small-sized Italian winemaker (Petti and others 2006). In this way some preliminary comparative considerations concerning the two methodologies, notably CF and LCA, were also possible.

The main goal of this LCA case-study was to identify the most impacting life-cycle stages. The functional unit chosen was a bottle (750 mL) of organic red wine (Montepulciano d’Abruzzo), including primary packaging (glass bottle, shrink cap, cork and label) and secondary packaging (corrugated cardboard box, PVC film and wooden pallet). The farm analyzed has 12 hectares of vineyard, 5 of which cultivated with Montepulciano d’Abruzzo grape. The average yearly production of Montepulciano grapes is about 70 tonnes. The yearly production of wine is about 50,000 liters, part of which (75 %) is bottled, whilst the remaining is sold in bulk. The winery cultivates grapes and processes them into wine following organic methods of production and it is monitored on a regular basis by an official control board according to the relevant regulation (EEC 1991). The winery’s activities include winegrowing and making, bottling and sale of the finished product to local (19 %), national (61 %) and international (20 %) markets. The distribution system uses: 38 tonnes lorry-trailers to transport the products to foreign countries; 7.5 tonnes lorries to transport within Italy; and 3.5 tonnes vans to deliver locally. All the above steps were included within the product system boundaries, while wine consumption, transport of auxiliary materials, and the product’s end-of life phases were excluded (Petti and others 2006).



**Fig. 4** End page (partial) of the International Wine Carbon Calculator, giving results in tables and graphs

Most of the inventory data were collected directly on site at the winery. The collection of all production process inputs and outputs resulted in a structured set of data grouping all the operations carried out and the amounts of substances (fuel, chemicals, etc.) used in the various processes, as well as the output released throughout the crop year analyzed, according to the various months (Petti and others 2005, Raggi and others 2005). When primary data were not available, processes included in Life Cycle Inventory databases were used. LCA processes and calculations were implemented through the GaBi 4 software.

The same set of originally collected data was used as a source for the data entered in the IWCC. The carbon calculator's default parameters and emission factors were left unchanged, with the exceptions listed below.

The data was added through the screens according to the areas of reference: Scope 1–3. Prior and during the data entry phase a few assumptions and choices were made, as described below.

Because the available data on the phases upstream of bottling refer to the overall quantity of Montepulciano wine

produced, these data were allocated on a mass basis between bulk and bottled wine (like in the LCA model), and the value shares allocated to bottled wine were used for data entry.

#### Scope 1

As regards mobile equipment, data on fuel consumption (diesel) for operating tractors and other equipment and for transporting workers to fields were entered; the carbon calculator allows the user to select the fuel type, but not the kind of equipment (tractor, lorries, etc); thus, fuel-specific CO<sub>2</sub> default emission factors were used in calculations, irrespective of the piece of equipment actually used.

At the winery grape stalks are routinely ploughed back into the soil as part of farm practice. The grape stalks are first spread across the ground, broken into smaller pieces with a flail and then ploughed back into the soil. This process makes it difficult to choose the input data as the software guidelines do not envisage this operation, but

only disposal at a regulated landfill with CH<sub>4</sub> recovery. Moreover, it was not possible to specify exactly the nature of the stalk degradation, i.e. whether this entailed methane production or simply aerobic degradation with the consequent formation of CO<sub>2</sub>. The fact that the simplicity of the farming method meant that the grape stalks were simply ploughed in at a shallow depth led us to consider this operation as producing aerobic degradation. Thus, we decided the process was linked to a short carbon cycle and therefore, in accordance with the protocol guidelines, there was no input data.

## Scope 2

The default CO<sub>2</sub> emission factor for the production of electricity was adapted to the Italian power mix: 668 g CO<sub>2</sub>/kWh (European Commission 2010). Since this emission factor is also inclusive of the transmission and distribution losses of electricity to the point of use, no specific correction factor for power transmission and distribution losses was entered in the relevant field of the IWCC. As a result, all GHG emissions related to power use were included in Scope 2 even though, in principle, the share related to distribution losses should be included in Scope 3.

## Scope 3

As regards packaging, since no specific data field was found in the IWCC for the bottle paper labels, the relevant data were entered as “paper” in the “Wine bags” category.

For transports, the overall amount of kilometers travelled by the different types of vehicles used for product distribution were calculated, based on information available for each of the main market areas to which the wine is delivered (regional, national and international): number of bottles delivered, average distance travelled from the firm to the final market, type of vehicle used and its loading capacity.

Among the wine-related products used, the only one for which a corresponding entry was found in the IWCC was bentonite. Therefore, it was not possible to enter the data on the other inputs, such as potassium metabisulfite, yeast, albumin. Similarly, it was not possible to enter any data on the chemicals and other inputs used in the bottling process (sodium hydroxide, nitrogen), or in agricultural practices (copper hydroxide, micronized sulfur, *Bacillus thuringiensis* bacteria, milk, glucose), because no relevant entries were found in the IWCC. It should be noted that this lack of inputs is also reported in other papers (Gazulla and others 2010), while in another study (Penela and others 2009) the impacts deriving from the so-called “chemical products” are of considerable importance. It would thus seem clear that a study on these components is necessary in

order to accurately quantify their importance as regards their impact in proportion to the overall wine product system. The mass of the input flows that we could not enter in the carbon calculator shows a percentage share on the total mass input of around 1 %. It should be stressed that in the original LCA implementation case-study as well most of the above input flows were excluded from the analysis because relevant data were not found in the available databases (Petti and others 2006).

Finally, the IWCC prompts the analyst to enter data on waste destined to leave the company. In our case, marc and lees—which are the only by-products leaving the company—instead of being disposed of, are delivered to a distillery for further processing into alcohol and other derivatives. Therefore, it was decided not to enter any data for these items. Indeed, a more accurate modeling would require an allocation process (or alternative approaches) to deal with the environmental burden shared by the main product and by-products; however, no allocation (or alternative option) seems to be possible in the IWCC.

After the data entry and all the relevant checks were completed, the GHG emissions summarizing the results of the study—which are automatically tabulated and plotted by the IWCC—were considered and analyzed.

## Results

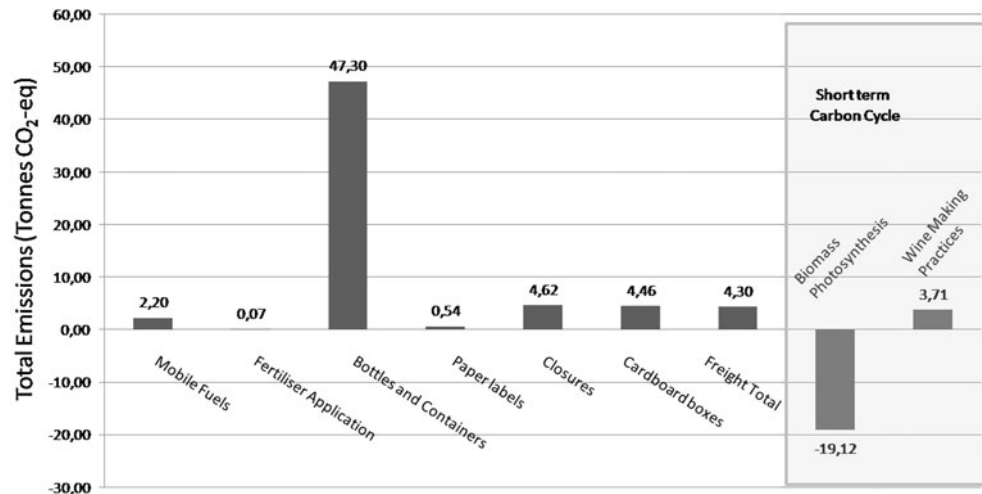
As regards the scope comparison, it emerged that, out of the total emissions generated, those deriving from products and activities that come from outside the company (Scope 3) are responsible for 95 % of the total global warming impact while a 4 % share is generated by the company’s direct emissions (Scope 1). Power consumption (Scope 2) is negligible (1 %) compared to the other components.

If we focus on the GHG emissions included in Scope 1, we can see that 97 % of those emissions are caused by the operation of mobile equipment and on-site transportation. The remaining is attributed to the emissions related to organic fertilizers (manure) spread on cultivated land.

If the breakdown of Scope 3 is considered, it should be highlighted that the contribution of packaging represents a large part of the emissions deriving from processes external to the company: globally 93 % (glass bottles: 77 %, closures: 8 %, cardboard boxes: 7 %, paper labels: 1 %). About 7 % of emissions are attributed to the distribution of the final product.

Figure 5 shows the absolute values of the GHG emissions referred to the reference crop year, for the various activities and processes carried out, irrespective of the scope. It can be clearly seen that the production of bottles is by far the most impacting issue (47 tonnes of CO<sub>2</sub>-eq, i.e. about 73 % of the total GHGs released). The other

**Fig. 5** General summation—GHG emissions released by the various activities and processes involved in the system analyzed



packaging materials are responsible for the emission of a further 10 tonnes of CO<sub>2</sub>-eq. (about 16 % of the total), thus definitely making wine packaging the most critical GHG contributor in this case-study. Other activities, such as product distribution, mobile equipment operation and power use, contribute marginally.

On the right side of Fig. 5, the CO<sub>2</sub> balance refers to the quantities sequestered by the vines' permanent structures (19 tonnes) and those released by wine-making activities (4 tonnes); both quantities are part of the short-term carbon cycle; therefore, as stated above and in accordance with the relevant protocol, they were not included in the balance. The calculator, indeed, envisages flow quantification (emissions and sinks) for the short-term carbon cycle but does not consider them in the balance calculations. In fact, two items are excluded: (i) that deriving from the process of photosynthesis (−19 tonnes); (ii) that deriving from must fermentation (+4 tonnes). Thus both items are calculated but neither are included in the balance as they are part of the short-term carbon cycle.

Although the calculator analyzed does not allow users to quantify the impacts with reference to a given functional unit (indeed, the software was designed to calculate the total emissions related to a company's output in the time period considered), we decided to further process the results obtained in order to refer them to the same functional unit defined in the LCA study (one 750-mL bottle). Starting from the overall quantity of emissions provided by the calculator (TGHGE: Total Greenhouse Gas Emissions) and the number of bottles of wine bottled in the reference year (TWB: Total Wine Bottles) we obtained the amount of CO<sub>2</sub>-eq per functional unit (TGHGE<sub>fu</sub>: Total Greenhouse Gas Emitted for functional unit) as follows:

$$\text{TGHGE}_{fu} = \text{TGHGE} / \text{TWB}$$

Table 1 summarizes the amounts of CO<sub>2</sub>-eq per functional unit released by the various activities and

processes involved in the system analyzed according to both the IWCC results and the LCA study results. As regards data related to LCA shown in Table 1, these have been obtained by rearranging GHG emissions reported in the original paper (Petti and others 2006) according to the entries provided by the IWCC; it should be stressed that in the original paper only the main flows, among those responsible for global warming, were reported, up to a cumulative contribution of 89 % of the total global warming potentially caused by the analyzed product system. Therefore it was not possible to identify in detail the minor items (e.g., those related to electricity generation) which are then cumulatively included in the residual "Others" entry; this entry also includes those specific items that did not match the IWCC entries.

## Discussion

We are well aware that a direct comparison of the results obtained by implementing LCA (limited to the Global Warming Potential results) (Petti and others 2006) and CF to this case-study, despite being mainly based on the same original data collected on-site, may have a limited scientific meaningfulness because modeling was not exactly the same in both cases. Nevertheless, we wish to underline that there were some similarities between the two instruments used as regards the relative results obtained. Indeed, when the LCA results for GWP (Petti and others 2006) are examined, it emerges that by far the greatest contribution in terms of emissions (more than 70 %) comes from packaging (in particular: the glass bottle), followed by product distribution and agricultural operations. Moreover, other studies confirm these conclusions (Fearne and others 2009; Kerner and Rocher 2009).

However, if we consider the quantity of GHGs expressed as an absolute value in kg of CO<sub>2</sub>-eq referred to the



**Table 1** Summary of the GHGs (kg CO<sub>2-eq</sub>) per functional unit released by the various activities and processes considered in the two assessments of the case study considered

	Carbon footprint software			LCA case-study (Petti and others 2006)	
	tonnes CO <sub>2eq</sub>	kg CO <sub>2eq</sub> per FU	%	kg CO <sub>2eq</sub> per FU	%
Scope 1					
Mobile fuels	2.20	0.044	3.4	0.059	7.6
Fertilizer application	0.07	0.001	0.1		
Scope 2					
Electricity	1.00	0.020	1.6		0.0
Scope 3					
Bottles and containers	47.30	0.946	73.3	0.468	60.4
Bottle labels	0.54	0.011	0.8		
Closures	4.62	0.092	7.2		
Fiber packaging	4.46	0.089	6.9	0.020	2.6
Freight total	4.30	0.086	6.7	0.099	12.8
Other				0.129	16.6
Total	64.49	1.290	100.0	0.775	100.0

functional unit then clearly the results differ to a sometimes considerable extent. In fact, Table 1 illustrates how certain items cannot be directly compared because they are grouped differently. We should note that even where the total absolute value is concerned the IWCC gives a total of approx. 1.290 kg CO<sub>2-eq</sub>/FU as against approx. 0.775 kg CO<sub>2-eq</sub>/FU in the LCA study. With reference to the emissions associated with the bottle, being the quantity (mass) of glass used equal, it is clear that the differences in the amount of emissions can be attributed to different related emission factors.

Nevertheless, some shortcomings emerged during the CF implementation. As the IWCCP authors themselves recognize (FIVS 2008), the list of products and inputs available is limited to just a few wine-related products, while chemicals and other inputs used in the other life-cycle stages (viticulture, bottling) are completely missing.

As expected, most default model parameters and assumptions (for example: emission factors, different units of measurement from those of the SI) are closely related to the local conditions of the Countries/Regions of the organizations that developed the tool. However, with limited software management skills, some parameters (e.g., power mix emission factor) can be adapted to other regions. Nevertheless, the tool would be more practical if these parameters could be entered more easily, even by non-experts.

When multiple products or by-products (co-products) are obtained in the same process, specific modeling options, such as allocation or system expansion, may be required. For instance, if one refers to the case study discussed here, burden allocation was needed among wine-making by-products (e.g., marc, lees) and the main product

(wine), or between bottled and bulk wine. Although still debated, allocation and system expansion options are well developed in commercial LCA software and can be relatively easily implemented. Instead, these options do not seem to have been considered in the IWCC, probably as a result of the predominantly company-oriented approach of this tool. Similarly, if wastes are recovered, the environmental impacts that are avoided by eliminating the production and use of alternative substances or products should be credited to the system. For instance, in this case study, grape stalks are recovered by spreading them on agricultural land as a soil improver. This can be conventionally modeled by system expansion; however, in the IWCC the impact thus avoided could not be credited to the wine product system.

In the IWCCP, Scope 1 and 2 are considered to be the only ones directly controlled by a firm's management. Actually, a firm's strategic choices can often affect the environmental impacts of their products in the upstream and downstream supply-chain stages (e.g., by selecting more environmentally-sound raw materials, facilities or logistics solutions, or by designing their products (or related packaging) to make them more easily recycled). In fact, a fully integrated product-oriented (rather than company-oriented) approach would be more effective in making companies fully aware of their role in determining the environmental performance of their products and avoiding environmental burdens being shifted from one life-cycle stage to another.

Moreover, even though global warming is certainly a serious and significant environmental issue, on which a number of stakeholders' concerns are focused, impacts may also be generated on other environmental issues. The

sole consideration of the greenhouse effect in evaluating strategic options of a company—and, therefore, in guiding the purchasing decisions of consumers—may result in shifting environmental impacts from global warming to another issue, instead of improving the overall environmental performance. For instance, in the agricultural stage (e.g., viticulture), if we consider organic versus conventional farming, the former usually requires a larger amount of mechanical operations than the latter (e.g., for mechanical weeding as opposed to chemical solutions), thus potentially causing a greater impact on global warming produced by fuel combustion. However, this might be offset by a lower impact in terms of ecosystem and human toxicity, as a result of reduced spreading of herbicides. Therefore, focusing merely on global warming would not highlight this impact shift and this could be considered a serious limitation of the CF approach.

The decision of whether or not the CF methodology, which takes into account a single impact category, should be preferred to that of the LCA is currently extremely important (Weidema and others 2008) and has not yet been resolved. The most important aspects are, in fact, related to the perceived urgency of the issue of global warming and to the completeness of the LCA method. Any attempt to reduce and streamline a methodology like LCA to take into account only those aspects linked to potential global warming would involve dismissing and neglecting a whole series of information that should not be ignored even if they are difficult to understand for a hypothetical “average consumer”.

## Conclusions

Although climate change is not the only environmental issue that society faces today it has emerged as one of the most critical current issues. Like other industries, the wine industry has been increasingly impelled by market and regulatory drivers to assess, reduce and communicate carbon emissions. The need to develop a consistent and objective methodology has been appreciated by some winemakers' organizations as well as the OIV and they have set about developing an *ad hoc* protocol and instrument. This study implemented this carbon calculator to a wine product which had previously undergone LCA, with the aim of testing the tool and highlighting both its potential and limitations with a view to providing decision-makers with some elements to adjudicate its suitability as an official tool.

The calculator separates the emissions into three levels: Scope 1 (a company's direct emissions), 2 (purchased energy) and 3 (emissions related to “upstream” activities along the supply chain). By combining these scopes in

different ways users can obtain CF both at the enterprise and product levels.

However, the instrument is noticeably affected by an enterprise-oriented, rather than a product-oriented, approach, which is reflected, for example, in the impossibility of including the stages downstream the product distribution stage (use and end-of-life) in a product-related analysis or of relating the assessed impacts to a functional unit, understood as the amount of function provided by the product itself. Furthermore, the tool is unable to deal with the multi-functionality issue by means of suitable modeling options (such as allocation, or system boundaries expansion).

Moreover, some treatment options for residuals (e.g., burial of stalks in the field), or certain agricultural inputs or subsequent processing inputs cannot yet be entered in the analyzed version of the software.

Overall, the software seems easy to use, since it is based on a popular and well-known commercial spreadsheet, but has poor flexibility, since modification of the pre-set parameters (e.g., emission factors) needed to adapt a study to geographical areas other than those for which the original instrument was designed, requires certain technical skills.

As regards the results obtained, despite a few differences in framework and modeling, the results concerning global warming are quite consistent in relative terms. As expected, absolute results are rather dissimilar, given the different assumptions, parameters and modeling choices on which the two tools are based. To summarize, the carbon calculator's lack of accurate baseline data was confirmed and the need for further improvement and adaptation to additional contexts was highlighted.

A critical limitation lies not so much in the tool itself but more in the CF methodology which concentrates on a single impact category (Global Warming). LCA, indeed, by considering a range of environmental issues, as well as a complete life cycle approach, is more effective in avoiding the shift of environmental burdens and impacts from one life-cycle step to another, or from one environmental concern to another. On the other hand, CF seems to be more suitable as a marketing tool, given its focus on a single indicator which can be more easily communicated to unskilled people.

We feel, therefore, that the study which this paper has started should be continued by broadening the research boundaries (more companies and products) and diversifying the characteristics of the sample (larger companies). In this way a more accurate definition of the variables of interest (production stage or inputs) which contribute the greatest emissions in the chain, can be more precisely defined.

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