Eco-innovation and benchmarking of Carbon Footprint data for vineyards and wineries in Spain and France

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ABSTRACT

Environmental sustainability in the wine sector has become a priority, as a result of both the growing interest in environmental issues and the consumer's demand for more information regarding the environmental impact of the products they purchase. In this context, the use of carbon footprint as an indicator to assess and report the environmental burdens associated with wine production has gained a role of primary interest. The present study has the aim of improving the wine sector's sustainability by providing inventory data on wine production systems from a total of 18 wineries located in major wine-producing regions in Spain and the South of France. The main novelty of this paper is: the corporate carbon footprint approach, the greater number of wineries studied, the diversity of location of those wineries, the detail of data presented and the identification of the best reference flow for vineyards. Data was statistically analysed. Vineyard consumptions are usually related to the area of cultivation. However, although 1 hectare of vineyard or 1kg of harvested grape could both be considered good reference flows for vineyard processes, this study shows a greater standard deviation of average data calculated per ha rather than per kg. Impact results show a major contribution of the winery phase to the corporate carbon footprint (73%), mainly due to glass production for bottling (45.6% contribution) and electricity consumption (9.2%). In the vineyard phase, contribution comes mainly from diesel production and combustion due to field works (11.3%) and the use of phytosanitary products (6.0%). The results revealed that with the establishment of best practices and with optimized resource consumption, the corporate carbon footprint values can be reduced by almost 25%. The comparative results presented can be used as a reference that will enable wineries to compare their impacts to the average, to identify in which aspects they are within the average and which aspects they are outside the average and whether these aspects are significant to their carbon footprint. This may encourage wineries to adopt measures for Eco-innovation through carbon emission reduction.

1. Introduction

Wine production constitutes one of the most ancient economic sectors and is still at present a very important agri-food activity in Europe. Among the main worldwide producers, Southern European countries, Spain and France, currently have the highest surface area of territory dedicated to wine production (Salvat & Boqué, 2009). Grape growing accounts for a large majority of agricultural activities in regions where wine production is concentrated and, similarly to other agricultural activities, it has a significant impact on the environment due to the use of fertilizers, pesticides, water and energy, soil erosion and land use, and to the production of substantial amounts of organic waste (BREF of food, drink and milk industry, 2006).

In the past decade, pressure from environmental authorities and an increasing interest from consumers and foreign importers in environmental issues leading to a higher demand for information regarding the environmental impact of the products they purchase, have led to new appellations and quality standards resulting in a steady decline of wine production in Europe (OIV, 2012). In order to keep up with the current demand trends and to improve market quota, competitiveness and consumer satisfaction, a growing number of stakeholders in the wine sector has started to analyze and disseminate environmentally relevant results (Szolnoki, 2013). Consequently, environmental sustainability has become a priority for those involved in the wine supply chain (Forbes et al., 2009).

In this context, the application of life cycle assessment (LCA) as a standardized environmental management tool (ISO 14040, 2006; ISO 14044, 2006) has gained a role of primary interest within the extensive literature, regarding assessment of the different environmental burdens associated with wine production for moving toward sustainable grape growing and wine production practices (Rugani et al., 2013). Wine LCA studies vary on the type of wine (Fusi et al., 2014, Pattara et al., 2012; Amienyo et al., 2014) the country where wine is produced, such as Spain (Vázquez-Rowe et al., 2012a; 2012b), France (Bellon-Maurel, V., et al., 2015), Italy (Benedetto, 2013; 2014; Iannone et al., 2016; Marras, S., et al., 2015), Portugal (Neto et al., 2013), Australia (Thomas, 2011), Canada (Point et al., 2012; Steenwerth, K.L., et al., 2015) and the life cycle stages included in the study, cradle to grave (Gazulla et al., 2010) or cradle to gate (Pattara et al., 2012). Although LCA has proven to be useful to quantify the environmental burdens associated within life cycle stages of wine, it has disadvantages due to its wide scope in terms of system boundaries or multiple impact categories.

Certainly, in Europe, there is a huge ongoing effort to improve and promote the use of LCA in different sectors, including the wine sector, through the PEF[1] and OEF[2] methodologies of the Single Market of Green Products Initiative[3]. However, there is an even higher worldwide trend of simplification (Baitz et al., 2013; Bala et al., 2010) focussing on a single indicator, carbon footprint, relevant to global warming, which is internationally considered as critical environmental concern (Pattara et al., 2012; Weidema et al., 2008). Being a one-indicator methodology doesn't mean that there are no methodological pending issues in carbon footprint calculation; for instance, the accounting of organic carbon is of great importance (Arzoumanidis et al., 2014). Carbon footprint may be assessed at product level, following the LCA methodology for only this one impact category and following standards such as: PAS 2050 (2011), ISO 14067 (2013) or GHG Protocol for products (2011). It can also be assessed at corporate level, following standards such as: ISO 14064 (2006) or GHG Protocol for organisations (2004).

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[1] Product Environmental Footprint
[2] Organisation Environmental Footprint
[3] http://ec.europa.eu/environment/eussd/smgp/

Corporate carbon footprint can be calculated at three scopes (GHG corporate protocols, 2004 and 2011): 1) direct emissions, 2) emissions from electricity production and 3) indirect emissions upstream or downstream on the production chain. There are a number of industrial sectors which have high greenhouse gas (GHG) emissions at their facilities (mainly due to combustion) or because of their intensity in electricity use. Those which are affected by EU Directives and the dominant scopes are scope 1 and 2 (DIRECTIVE 2003/87/EC). The rest of the economic sectors have diffuse emissions and are normally found within the scope 3. In order to calculate any contribution (emission factor) from a process within scope 3, such as the emissions produced due to the production of fuel or a certain raw material, or the management of a certain waste, there is a need to use the LCA methodology (GHG corporate protocol, 2011). Therefore, whether a complete LCA is needed or only a product carbon footprint or a scope 3 corporate carbon footprint, there is somehow a need for LCA methodology.

The wine sector has started to follow the trend for simplification. Some carbon footprint studies of wine production systems have been published, either product (Vazquez-Rowe et al., 2013; Cholette and Venkat, 2009; Pattara et al., 2012) or corporate (Marras, S., et al., 2015; Penela, et al., 2009), and carbon calculators have also been developed for the wine sector (IWCC; WFA, 2011; Colman & Päster, 2009). . The corporate studies refer to one vineyard in Italy (Marras, S., et al., 2015) and a winery in Spain (Penela, et al., 2009).This last study does not present the inventory data.
Most of the wine literature refers to product LCA studies (not really carbon footprint), thus providing a picture of the environmental profile of the wine sector and identifying the main hotspots throughout the wine production chain. Nevertheless, a review of those studies revealed that they have been focussing on either only one type of wine from only one winery (Neto et al., 2013; Fusi et al., 2014; Benedetto, 2013; Vázquez-Rowe et al., 2012b) or a higher number of wineries but within a specific region or production phase: vineyards in Galicia (Vázquez-Rowe et al., 2012a) and wineries in La Rioja (Gazulla et al., 2010). And, where multiple types of wine and different regions were studied, most of the inventory data was gathered from previously published studies, with different years of production and system boundaries (Vázquez-Rowe et al., 2013).
The value of the present paper, compared with the previous literature, is in the corporate carbon footprint approach used, the statistical treatment of inventory data from a greater number of wineries than previously published, the location of these wineries (different regions in Spain and France) and different types of wine (red and white).

Hence, the main objective of the article is to provide inventory data on wine production systems from 18 wineries (3 cooperatives) located in 2 countries, 7 regions, 14 denominations of origin (see Table 2) in order:
  (i)   to be used as background data for corporate carbon footprint of wineries or product carbon footprint of wine and derived products;
  (ii)   to highlight the main hot spots contributing to the carbon footprint of this sector;
  (iii)   to show opportunities for improvement of sustainability and competitiveness within the wine production system;
  (iv)   to help wineries benchmark and monitor their environmental performance against the mean values obtained.
An internal critical review of the collected inventory data and a comparative statistical study of chemical and energy consumptions per hectare of vineyards and per kg of grapes have also been performed.

2. Materials and methods

2.1. Methodology

Corporate carbon footprint following the ISO 14064 standard methodology was used to analyse the GHG emissions from 18 wineries. This method is a bottom-up process analysis, which begins with

collecting and analysing a great deal of specific information from all the processes involved in the production of 1 bottle of wine. Thus, quantities of material and energy consumptions/inputs and emissions/outputs per one year was gathered from all involved companies and processes.

The bottom-up process analysis is limited, and truncates life-cycle stages further upstream. This phenomenon is well known as "truncation errors" (see examples for wood and steel by Lenzen and Treloar, 2002 and Lenzen and Dey, 2000, respectively) and can be ascribed to the finite system boundary. Unfortunately such truncation errors are systematic and not stochastic (Lenzen, 2000), thus rendering any comparisons or statements about relative proportions invalid (see Lenzen and Treloar, 2003). One approach to overcome such systematic truncation errors is to combine bottom-up process analysis with top-down input-output analysis into a hybrid Life-Cycle Assessment method (Heijungs and Suh, 2002; Suh, et al., 2004; Suh and Huppes, 2005; Suh and Nakamura, 2007). Such a hybrid assessment combines the best of both worlds - specificity and completeness (Bullard, et al., 1978; Moskowitz and Rowe 1985); the truncation errors of process analysis are avoided, as well as the aggregation errors of input-output analysis (Gibbons, et al., 1982; Kymn ,1990; Murray, 1998; Lenzen, 2011; Steen-Olsen, et al., 2014). Hybrid assessments of agricultural production systems have been undertaken before (ie. Wood, et al., 2006). Nevertheless, this hybrid Life-Cycle Assessment method is not within the scope of the present paper, although it can be used in future works.

Corporate carbon footprint methodology (ISO 14064 and GHG corporate protocols, 2004 and 2011) consists of calculating direct and indirect GHG emissions produced, as a result of the company's activities during one year. Direct emissions refer to emissions taking place in the company itself (ie. emissions from fuel combustion), while indirect emissions take place elsewhere (ie. emissions from the production of electricity purchased by the company). To quantify indirect emissions from purchased electricity (scope 2), goods and fuels, transport and waste management (scope 3), life cycle methodology (ISO 14044) is used. In this study, indirect emissions were calculated from company data and by using emission factors from LCA databases (ie. ecoinvent, Thinkstep and ELCD).

According to the standards, companies are free to include or exclude scope 3 indirect emissions in their corporate carbon footprint. In this study, scope 3 categories 1 (purchased goods and services), 3 (fuel and energy related activities, not included in scopes 1 and 2) and 5 (waste generated) were included in the study, while other categories, like business travel, the commuting of employees and product distribution were out of the scope due to their probably low influence or the difficulties on data gathering from the company.

2.2. System description

The inventory data has been collected from various types of wine production processes (2013 campaign), predominately from red wine production (by 80%), using different kinds of grapes such as Tempranillo, Chardonnay or Grenache among others, in 18 wineries (3 wine cooperatives) with wineyards in 7 production regions and 14 denominations of origin (Table 2 and Figure 1). The winery cooperatives are associations which produce wine, from a great number of affiliated vineyards, and provide other services to their affiliated vineyards (ie. to supply fertilizers and phytosanitary products, to rent machinery or provide other services to them). Vineyards affiliated to cooperatives can have different denominations of origin (DO). Thus, cooperatives produce wine from different DO, but the data on Table 2 corresponds only to the indicated DO.

Specifically, data has been collected from corporative carbon footprint studies within the scope of the CO2 Vino and VINECO projects, conducted with the aim of improving the wine

sector's sustainability. A specific number of wineries had to be chosen from the regions determined by each project: in CO2 Vino should be from Galicia (2), Castilla La Mancha (5) and Murcia (1) and in VINECO from Midi Pyrenees (4), Langedoc-Roussillon (2), Catalonia (2) and Balearic Islands (2) (see Figure 1). The process of choosing the participating wineries was as follows: 1) information about the project was sent by email to all wineries in the involved regions; 2) a seminar was held in each region to explain the project and the benefits of participating; 3) wineries that were willing-to-participate had to register through a website; 4) all companies registered were contacted to be sure that they understood their duties (data providing and scheduling); 5) unreliable companies were excluded from the selection process; 6) a raffle was held amongst the remaining wineries from the same region. The wineries were not selected to be representative of the involved regions but to be reliable on gathering and providing rigorous data within the schedule.

Figure 1. Location of wineries studied in the scope of the study (source: modified from Mapbox, 2015).

The system boundaries of this analysis include all major material and energy flows associated with life cycle stages such as grape growing, wine making and bottling and packaging (Figure 2). The wine production system involves two main subsystems: vineyard (i.e., cultivation and harvesting of the grapes) and winery. Water use, on vineyards and in wineries, was excluded due to lack of data. As it varies a lot from one year to the other, transportation was either not included in the system boundaries, except the transport of harvested grapes to the wine production facilities. Primary data was collected through the use of questionnaires and personal communication with representatives of the wineries. These questionnaires involved main direct inputs and key operational aspects of the vineyard, wine making, bottling and packaging processes of wine production. All questionnaires were examined and compared in order to find values far from the mean and to ensure the quality of data. After checking, very different values were noted, as production practises differ a lot from one company to the other.

In order to obtain the necessary data for the study, a questionnaire was developed (using the experience of the authors in a previous EU financed project (LIFE 08 ENV/E/000143). The questionnaire was divided in 3 excel sheets: general aspects, vineyard (asking data about consumptions and emissions for each delivering farm) and winery (asking data about consumptions and wastes during the winemaking process and the bottling) (see Table 1). Visits to the wineries to

help filling the questionnaire were performed, together with subsequent contacts through e-mail and phone calls to address the pending issues.

Table 1. Type of information asked in the questionnaires.

General Aspects	Vineyard	Winery
Winery name Year of data Denomination of origin Contact person Process flow diagram Total production of wine 　　Own wine (L) 　　Wine bought (L)	Farm name and location Cultivated area (ha) Types of grape and amount produced (kg) Diesel consumption in vehicles (own / rented) (L) Transport of grape to the winery (km) Fertilizers, type and quantity (kg) Phytosanitary products, type and quantity (kg)	Diesel Wastewater, amount and pollution parameters (L, g/L) Electricity (kWh) Refrigerant gases, type and amount (kg) Wine additives, type and amount (kg) Bottles, type of glass and weight (kg/bottle, total kg) Wastes, type and amount (kg)

For corporate carbon footprinting in wineries, data is collected per year (from September the 1st to August the 31st). As some wineries are much bigger than others, for comparability sake, in this paper data and results will be given per kg of grape, per hectare of cultivated land or per bottle of wine. However, these results must not be taken as product carbon footprints.
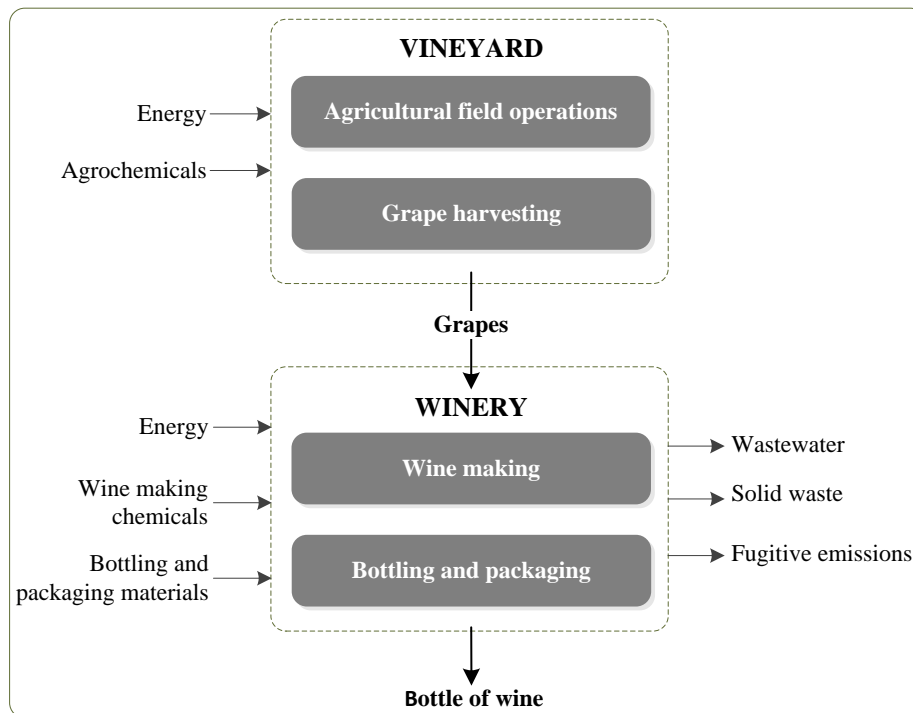

Figure 2. System boundaries and Flow diagram of the wine production system

Table. 2. Characteristics of the wineries participating in the study

Winery region	Denomina-tion of origin (DO)	Total L of wine produced per year	Total ha	Total kg of grape	Type of grape	Type of wine produced in the winery	Source of data
Galicia (ES)	Rías Baixas	20000	2.8	32000	albariño	white	CO2 Vino
	Rías Baixas		3.5	38500	albariño	white	CO2 Vino
Murcia (ES)	Jumilla	3391334		6104088	Mourvèdre, cabernet sauvignon, syrah, tempranillo, petit verdot, macabeo, airén	red/white	CO2 Vino
Catalonia (ES)	Penedes	34441	24	120000	macabeo, chardonnay, riesling, gewürztraminer, muscat, merlot, parellada, xarello, pinot noir	red/white/rose/sparkling	VINECO
	Costers del Segre	2645194	1865	16923500	chardonnay, cabernet sauvignon, syrah, tempranillo, sauvignon blanc, albariño, merlot, xarello, pinot noir	red/white/rose/sparkling	VINECO
Balearic Islands - Menorca (ES)	Vi de la Terra	17000	4.5	25000	merlot, chardonnay, syrah, muscat	red/white/rose/sparkling	VINECO
	Vi de la Terra	60000	10	111000	merlot, chardonnay, syrah, cabernet sauvignon, macabeo, tempranillo	red/white/rose/sparkling	VINECO
Castilla la Mancha (ES)	Uclés	596500	117	700000	tempranillo, chardonnay, cabernet, sauvignon blanc, syrah, merlot	red/white	CO2 Vino
	Uclés	225000			Tempranillo, macabeo	red/white	CO2 Vino
	Uclés	16723417	2462.3	21601847	Airén, tempranillo, chardonnay, sauvignon blanc	red/white	CO2 Vino
	Uclés	2564180	583.6	3663610	tempranillo, Cabernet-Sauvignon, Syrah, Merlot, Sauvignon blanco verdejo	red/white	CO2 Vino
	Dehesa del Carrizal	56709	25	117875	tempranillo, chardonnay, cabernet sauvignon, syrah, merlot, petit verdot	red/white	CO2 Vino
Midi Pyrenees (FR)	Gaillac/Côtes du Tarn	328600	67.2	41405	Sauvignon, mauzac, merlot, duras, braucol, syrah, prunelard, gamay, muscadelle, loin de l'oeil	red/white/rosé	VINECO
	Gaillac/Côtes du Tarn		33.4	252180			VINECO
	Gaillac/Côtes du Tarn	8907923			Sauvignon, mauzac, merlot, braucol, syrah, gamay, muscadelle, loin de l'oeil, Malbec, cabernet, cabernet franc, négrette, tannat	red/white/rosé	VINECO
	Gaillac/Côtes du Tarn		20	200733	muscat petit grain, muscat, syrah, carignan, grenache, mourvèdre, cinsault, cabernet franc, sauvignon, cabernet sauvignon		VINECO
Langedoc-Rousillon (FR)	Minervois, Pays d'Hérault	31850	11.21	41405	syrah, cinsault, carignan, grenache blanc, marsanne	red/white/rosé	VINECO
	Côtes du Roussillon, Côtes Catalanes	8119821			syrah, carignan, grenache blanc and noir, roussanne, chardonnay,macabeo, malvasie, mourvèdre, merlot, muscat petit grain and alexandrie	red/white/rosé	VINECO

3. Results and Discussion

3.1. Inventory data for Vineyard subsystem

This stage includes the agricultural field works: application of fertilizers, irrigation, phytosanitary treatments, harvesting of grapes and transportation of harvested grapes to the winery.

Aspects contributing to the environmental impacts of agriculture refer to the energy consumption and emissions derived from crop growing processes, such as the use of fertilizers, pesticides or herbicides. Many of these inputs are related to the area of cultivation. Thus, 1 hectare of vineyard or 1kg of harvested grape could be both considered, in principle, good reference flows. The minimum, maximum, mean and standard deviation values obtained for the key processes in the vineyard stage are presented in Table 3.

Table 3. Values from 18 wineries per kg of grape and per ha of vineyard

Vineyard Inputs	Per kg of grape				Per ha of vineyards			
	Min.	Max.	Mean	Std.dev.	Min.	Max.	Mean	Std.dev.
Fertilizers								
Organic fertilizer [kg N][a]	0.00003	0.0102	0.0048	± 0.0037	0.10	61.00	29.9	± 26.7
Urea based synthetic fertilizer [kg N] [a]	0.002	0.006	0.0037	± 0.0019	9.86	30.95	46.0	± 17.4
Phosphorous based synthetic fertilizer [kg P_2O_5][b]	0.0036	0.0357	0.0114	± 0.0137	20.00	213.70	70.1	± 81.6
Phytosanitary products								
Sulphur based fungicides [kg]	0.00015	0.022	0.007	± 0.008	0.72	175.31	42.92	± 55.59
Unspecified fungicides [kg]	0.00018	0.0046	0.002	± 0.001	1.50	29.19	12.40	± 11.94
Herbicides [kg]	0.00021	0.0017	0.0007	± 0.0005	1.49	10	5.19	± 3.65
Insecticides [kg]	0.00011	0.0009	0.0003	± 0.0004	1.01	10	3.32	± 4.45
Energy								
Diesel [L]	0.012	0.06	0.031	± 0.015	44.61	474.84	221.2	± 144.0
Electricity [kWh]	0.0009	0.077	0.045	± 0.028	10	568	352.4	± 207.0

[a] Values were expressed in kg of nitrogen (N) content of each fertilizer product
[b] Values were expressed in kg of phosphorus pentoxide (P_2O_5) content of each fertilizer product

From the present study, results show that inventory data per ha has a significantly higher deviation compared with data per kg of grape (see Table 3). This is likely due to the variation of agricultural fieldwork and application of agrochemicals, mostly depending on the intensity of the cultivation, measured as the number of vines planted per ha, which probably depends on the soil quality and climate conditions. Hence 1 kg of grape harvested is considered as the best reference flow to be used in our study and it is clearly related to the amount of wine obtained afterwards in the winery (0.75 L wine/kg grape) (Báguena, 2014 and Calvo, 2014).

Electricity consumption in this phase is due to irrigation systems. Organic fertilizers used in vineyards are composed of compost and manure; therefore, as they are wastes from other production systems, no environmental burden will be assigned to their production when calculating the carbon footprint (GHG product protocol, 2011). Urea and phosphoric acid have been taken as proxies for calculation whenever synthetic fertilizers were reported, depending on whether they contain nitrogen or phosphorous in their chemical composition. For phytosanitary products a generic phytosanitary was used as a proxy, but in the case of sulphur based products, sulphur production was used.

3.2. Inventory data for Winery subsystem

This subsystem includes wine production, bottling and packaging processes. Processing 1 kg of grape yields 0.75 L of wine, which is equivalent to one standard bottle of wine (Báguena, 2014 and Calvo, 2014). The reference flow of this winery stage was defined as a 0.75 L bottle of wine. Results are shown in Tables 4 and 5.

Table 4. Inventory data for wine additives related to production of 0.75 L of wine

Input		0.75 L wine (standard bottle)			
Categories	Products [kg]	Minimum	Maximum	Mean	Std.dev.
Filtering material	Perlite	0.0045	0.01725	0.011	± 0.009
	Various[*]	0.00004	0.01125	0.003	± 0.004
Clarifying material	Bentonite	0.00028	0.00064	0.0005	± 0.0002
	Various[*]	7.85E-06	0.00213	0.0007	± 0.0007
Antioxidants	Sulphur	4.12E-06	0.0015	0.0007	± 0.0007
	Various[*]	1.32E-05	0.00141	0.00045	± 0.00061
Stabilizers	Polyvinylpolypyrrolidone[**]	-	-	0.00005	-
	Various[*]	0.000055	0.00067	0.0003	± 0.0003
Carbon dioxide	Carbon dioxide	0.000051	0.00262	0.0008	± 0.0012
Acidifiers	Citric acid	0.000005	0.00044	0.00014	± 0.00016
	Various[*]	0.00002	0.00033	0.00017	± 0.00022
Microfiltering material	Oxygen	0.000011	0.000016	0.000013	± 0.000003
Disinfectants	Chloride	1.01E-06	0.000050	0.000025	± 0.000035
Detergents	Caustic soda	0.00009	0.00022	0.00016	± 0.00010
	Various[*]	0.00022	0.00067	0.00322	± 0.00023
Nitrogen[**]		-	-	0.00004	-
Fermentation products	Ammonium phosphate	0.000022	0.000202	0.00015	± 0.00008
	Various[*]	0.00012	0.012	0.00315	± 0.00592

[*] *Chemical assimilated to the one named above in the same product category.*
[**] *Single available data*

Table 5. Inventory data in winery (without wine additives, which are shown in Table 4) related to production of 0.75 L of wine.

Inputs		Per 0.75 L of wine			
Products [kg]		Minimum	Maximum	Mean	Std. Deviation
	Hard Plastic[**]	-	-	0.00004	
	Plastic sheet (Bag in box)	0.0008	0.0032	0.0018	± 0.0009
	Glass	0.054	0.774	0.349	± 0.242
	Aluminium sheet (Bag in box)[**]	-	-	0.0009	-
	Cardboard	0.0034	0.0525	0.0289	± 0.0167
Energy					
	Diesel for transportation vehicles [L]	0.0002	0.0132	0.0065	± 0.0065
	Diesel for heating, water heating. process equipment [L]	0.00004	0.024375	0.0117	± 0.0107
	Electricity [kWh]	0.1193	1.8075	0.4425	± 0.4993
	Natural gas [kg] [*]	0.0002	0.0059	0.003	± 0.004
	Propane [kg][**]			0.0002	-
Outputs					
Wastes					
	Waste water [m³]	0.00072	0.0105	0.0034	± 0.0033
	Solid waste [kg]	0.00075	0.0375	0.0135	± 0.0140
	Residual glass [kg]	0.00001	0.984	0.1515	± 0.3675
Refrigerant gas recharge [kg]					
Fugitive emissions[**]	R22	-	-	8.48E-06	-
	R410a	-	-	1.21E-05	-
	R407	-	-	1.70E-06	-

[*] Assimilated to natural gas due to lack of information on the type of the gas
[**] *Single available data*

Electricity and glass consumption are the most significant issues by far (see Table 5). The amount of refrigerant gases recharge is very low, but it may have an important contribution to the carbon footprint.

3.3. Average carbon footprint results

Carbon footprint calculations from inventory data, both for vineyard and winery stages (Figure 1), were performed by using CO_2-eq emission factors. For data associated with the production of chemicals, these factors were taken from the GaBi6 professional database (Thinkstep, 2015); and for data related to other processes, such as direct and indirect N_2O soil emissions from synthetic and organic fertilisers or waste treatment, emission factors were obtained from IPCC 2007. They were calculated according to country and region specific characteristics.

The chosen global reference unit (RU) for the study has been one bottle of 0.75L of wine (which connects directly with the reference flows of both subsystems). Figure 3 shows the contribution of each stage within the overall average carbon footprint, which has been obtained as 0.85 kg CO_2eq per RU. The results have been obtained using the average data for the 18 wineries studied. Figure 4 shows the main contributors of greenhouse gass (GHG) emissions to each subsystem: vineyard and winery.
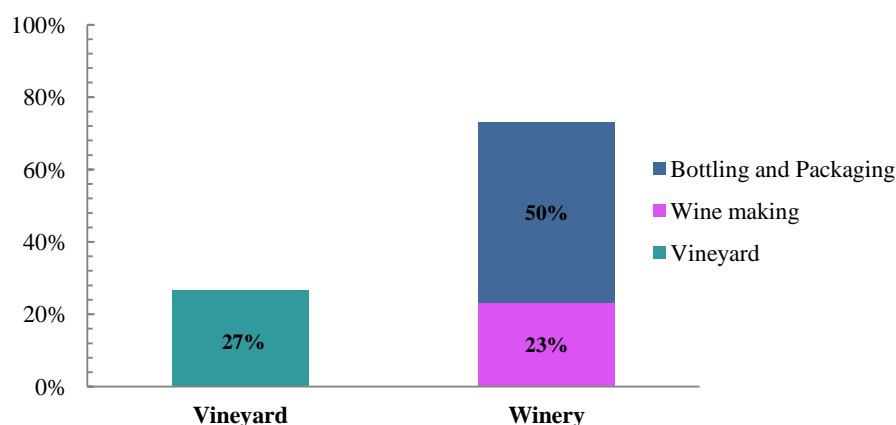
Figure 3. Relative contribution of vineyard and winery subsystems to GHG emissions per RU.
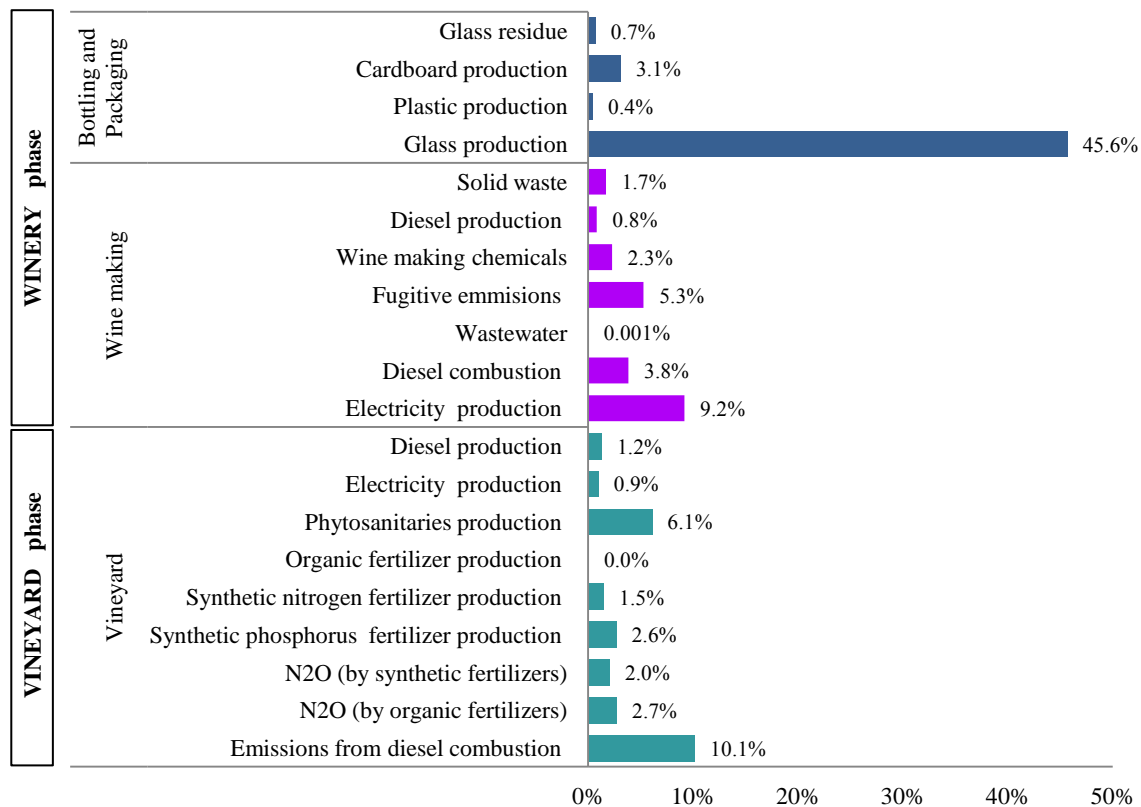
Figure 4 Relative contribution of the different processes to GHG emissions to the RU.

Bottling and packaging processes have a significant influence on the environmental performance of the overall winery subsystem, contributing to 50% of the GHG emissions (see Figure 3). The main contributor in this process is the production of glass, with an average contribution of 45.6% to the total carbon footprint, which is consistent with the results obtained by other researchers (Bosco et al., 2011; Fusi et al., 2014).

Electricity consumption and fugitive emissions appear as the subsequent largest contributors in the winery phase, adding on average 9.2% and 5.3% respectively (Figure 4). As seen from the results, wine additive products have a low influence. This may be due to the use of simpler proxy substances from LCA databases in order to find emission factors, instead of performing a life cycle assessment of each one of the more sophisticated chemicals used in wine making.

In the vineyards, GHG emissions are mainly associated with the combustion of diesel for agricultural field works, which is consistent with the previously reported studies in the recent literature (Benedetto, 2013; Villanueva-Rey et al., 2014). The emissions derived from combustion of diesel and production of phytosanitary substances are the most burdening processes in this phase, with an average relative contribution of 10% and 6% respectively to the carbon footprint (see Figure 4). The smallest GHG emission contribution in the vineyard comes from the production of electricity used for the irrigation of grapes. It has to be said that diesel is the main source of energy used for irrigation, not electricity.

As previously stated, both good and inefficient practices have been identified in the surveyed wineries. Table 6 presents the best and worst case results expressed in terms of kg CO_2-eq per RU. These results come from converting the inventory data into GHG emissions by using the correspondent emission factors.

Table 6 Benchmarks for contribution of each wine production process to the carbon footprint of 0.75 L of wine.

Vineyard	Min. [kg CO$_2$-eq]	Max. [kg CO$_2$-eq]	Mean [kg CO$_2$-eq]
Input			
Diesel production	0.004	0.021	0.011
Electricity production	0.0002	0.014	0.008
Production of phytosanitary substances	0.017	0.355	0,052
Production of urea based fertilizers	0.0053	0.02	0.012
Production of phosphor based fertilizers	0.0089	0.045	0.022
Output			
Emissions from diesel combustion for agricultural field operations	0.033	0.167	0.086
N$_2$O from application of organic fertilizers	0.0001	0.048	0.023
N$_2$O from application of synthetic fertilizers	0.0094	0.028	0.017
Total vineyard	*0.08*	*0.70*	*0.23*

Winery	Min. [kg CO$_2$-eq]	Max. [kg CO$_2$-eq]	Mean [kg CO$_2$-eq]
Input			
Electricity production	0.0212	0.3216	0.0783
Cardboard production	0.0031	0.0469	0.0261
Plastic production	0.0016	0.0059	0.0035
Glass production	0.0602	0.8633	0.3893
Diesel production	0.0001	0.0143	0.0069
Detergents	0.0004	0.0011	0.0043
Clarifying materials	0.0001	0.0014	0.0006
Oxygen	1.11E-06	1.62E-06	1.31E-06
Fermentation products	0.0001	0.0122	0.0033
Acidifiers	0.00014	0.00422	0.0017
Antioxidants	0.00001	0.00185	0.0007
Stabilizers	0.0003	0.0032	0.0017
Carbon dioxide	0.00002	0.00125	0.00038
Disinfectants	1.28E-06	6.40E-05	3.20E-05
Nitrogen	2.42E-06	2.42E-06	2.42E-06
Filtering materials	0.00220	0.01367	0.00684
Output			
Glass residues	4.81E-07	0.0364	0.0056
Municipal Solid waste	0.0007	0.0386	0.0144
Fugitive emissions	0	0.045	0.045
Waste water	1.01E-06	1.55E-05	4.78E-06
Emissions from diesel combustion	0.0001	0.0681	0.0326
Total winery	*0.09*	*1.48*	*0.62*
A bottle of (0.75 L) wine	**0.17**	**2.18**	**0.85**

Taking the universe of wineries studied and shown in Table 2, the mean winery would produce 3,886,397 bottles of 0.75L of wine per year, and the mean vineyard would produce 3,331,543 kg of grapes. The amount of wine is higher than the amount which would come from harvest, as the wineries buy grapes and wine from other sources to complement the wine production.

The carbon footprint values of investigated wineries per RU (0.75L of wine) in the present study are found in the range between 0.17 and 2.18 kg CO_2-eq, the average being 0.85 kg CO_2-eq/bottle of wine. In current literature, product carbon footprint (cradle-to-gate) per bottle of wine ranges from 0.6 to 2.68 kg CO_2-eq (Bosco et al., 2011; Point 2008; Neto et al., 2013; Gazulla et al., 2010; Fusi et al., 2014). The minimum value obtained in this study falls below the reported range, but as will be explained later, is not achievable by all wineries. On the other hand maximum value is comparable with current literature.

The vineyard phase is the one presenting a wider variation. Carbon footprint results of the vineyard phase from previously published studies (Marras, S., et al., 2015; Fusi et al., 2014; Vázquez-Rowe et al., 2012a) are in the range of 0.169-2.5 kg CO_2-eq/bottle and our average value fits within the lower side of 0.23 kg CO_2-eq/bottle.

3.4. Best scenario results

The results have shown that the most contributing aspects are:

i. In the vineyard phase: combustion due to field works (10% contribution) and phytosanitary products use (6%).

ii. In the winery phase: production of glass (46%) and production of electricity (9%).

The benchmark values obtained from wineries reveal that, establishing best practices and with better resource consumption (diesel and phytosanitaries in the vineyard and weight of glass-bottle and electricity consumption in the winery), the carbon footprint could be about 0.64 kg CO_2-eq per bottle, achieving a reduction of 25%. This result was obtained by using the minimum values of the 4 most contributing aspects, reported in the inventory data from wineries (see Figure 5). In the case of glass production, a bottle of 300 g of glass (the lightest one from our study) was used as the minimum weight for a glass bottle in the wine sector (lower than the one resulting from the average values, which was 350 g/bottle).

It has to be mentioned that the complete set of minimum values reported probably cannot be achieved by any winery, because there are aspects related to climate and grape characteristics that can affect the consumptions. For example, the minimum amount of phytosanitary products reported (mainly fungicides) in this study corresponds to a winery located in Castilla La Mancha (centre of Spain), which is a dry climate region, a condition which prevents pests and, therefore, needs less fungicides than those required in a wet climate (Báguena, 2014). Thus, this minimum value of carbon footprint could not be achievable by any winery and should only be seen as an ideal.

On the other hand, in the winery phase, the reduction of glass and electricity consumption could be applied by all wineries, because these inputs are not affected by external aspects.
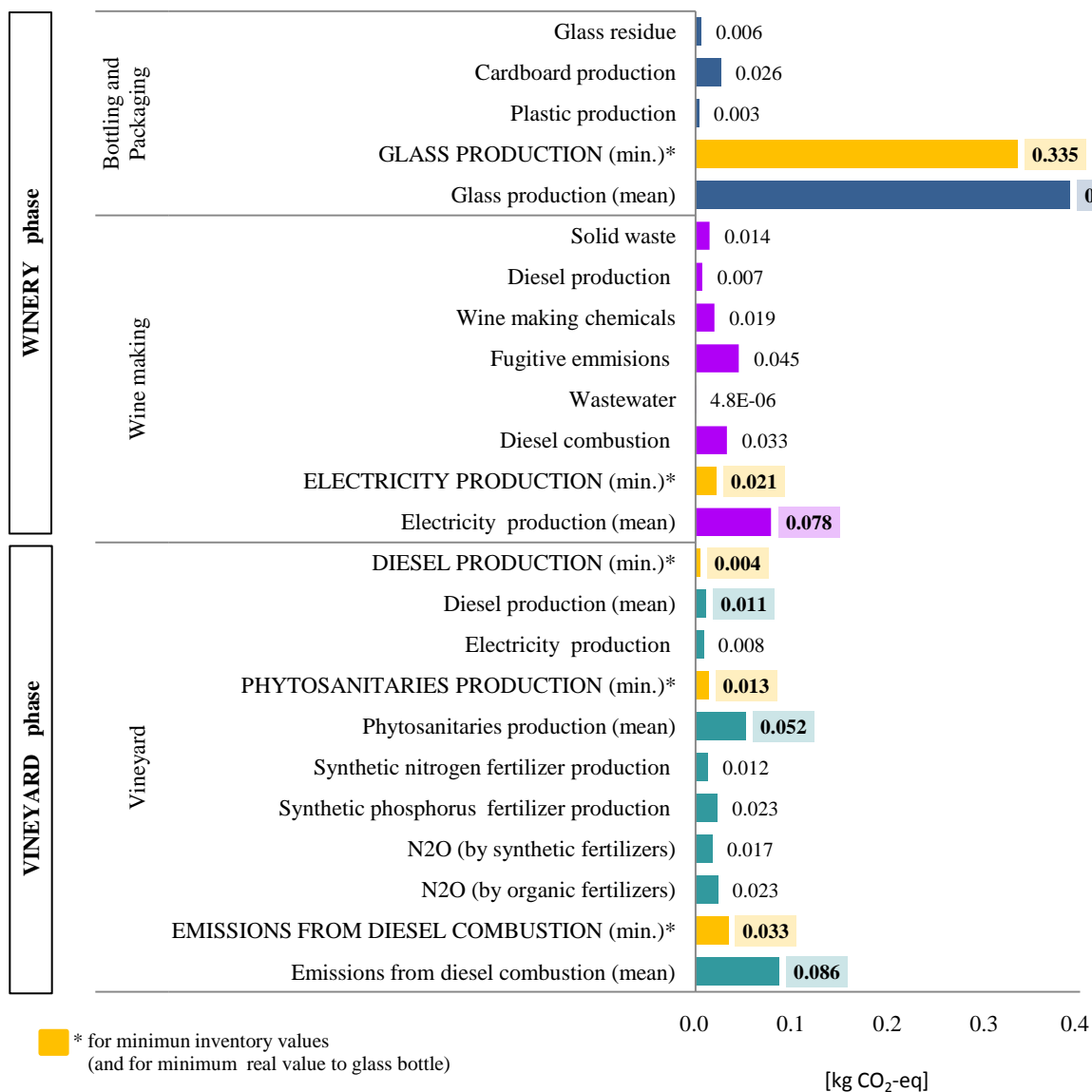
Figure 5. Comparison of average values of carbon footprint (in kg CO_2-eq) with some minimum consumptions reported.

3.5. Recommendations for process improvement

Some Eco-innovation actions that can be implemented to improve the environmental profile of wine and to reduce the carbon footprint are suggested, considering the findings of this study and other wine related studies in the literature (Table 7).

Taking into account the findings obtained from the current study, reasonable improvement options to reduce the environmental impact of wine making would be: the reduction of glass weight and the reduction of the use of phytosanitary products, which are the identified critical hotspots. Another recommendation would be to obtain more accurate individual inventory data, so that the results would

be as closer as possible to reality for each winery. They have more accurate data on inputs and outputs from the winery phase than from the vineyard phase, the latter being less important.

Table 7. Some measures for process Eco-innovation.

Issues	Improvement opportunities	References
Energy (in vineyard)	• Monitor and record water and energy use.	Our study
	• Inclusion of measures to reduce the energy intensity of field works by using efficient machinery and reducing the depth of soil works up to necessary.	Our study
Fertilizers and phytosanitaries (in vineyard)	• Ecological grape growing, reducing agrochemical use or substituting them with other less harmful ones	Our study; Aranda et al., 2005
	• Avoid chemicals remains being left inside the tank at the end of the application (of fertilizers and phytosanitary products) by adding water and spraying the diluted solution in the field. This will avoid overconsumption and prevent wastewater generation.	Our study
Energy (in winery)	• Reuse of hot water resulting from bottling sterilization process for secondary rinses or other activities that require hot water. It also offers savings on water usage, and reduces the quantity of wastewater generated	Malkin and Bahner, 1999
	• Use of cleaner alternatives to diesel.	Benedetto, 2013
	• Use of electricity with a higher portion of renewable sources.	Our study
Water consumption and Wastewater (in winery)	• Scraping off pipes during transfer operations in the winery (or pigging, very common in agrifood) can reduce water consumption as well as wastewater pollution by recovering products and avoiding mixtures. This technology has been recently adapted to wineries by Inoxpa and tests conducted by IFV[4] show a 50-80% reduction of water consumption of winery transfer operations.	Our study
	• Wastewater from the cellar can be managed in a better way by applying it to artificial wetlands (with less energy consumption than other treatments).	Our study
Glass consumption (in winery)	• Use of lighter bottles, with less material but the same mechanical resistance. In the brewing sector, the weight of the bottles has been reduced progressively to less than half.	Our study; Ardente et al., 2006; Point, 2008; Point et al., 2012; Colman & Päster, 2009; Amienyo et al., 2014
	• Changing the design of the bottles by using other materials instead of glass.	Amienyo et. Al. 2014
Glass waste management	• Increasing recycling rate of bottles at source.	Our study; Amienyo et al., 2014
	• Reuse of bottles, when possible.	Aranda et al., 2005.

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[4] Within the EU Project Winenvironment (http://www.winenvironment.eu/)

4. Conclusions

In this paper, a statistical analysis of the data collected from 18 wineries is presented. Data per hectare of vineyards and per kg of grapes was statistically analysed, showing that inventory data per 1 kg of grape has a much lower standard deviation.

Data used is of good quality, it covers small and large wineries in a large geographical area and also has precision, completeness and methodological coverage. The variability of data values is normal due to process specificities, depending on the region, climate and type of end product wine. It is the most detailed and wide-ranging paper found in literature showing corporate inventory data from 18 sites including both, vineyard and winery, with the same system boundaries, year studied and hypothesis.

The hotspots contributing to the carbon footprint of wine were highlighted, glass production for bottling being the most important one.

The main novelty of this paper is the corporate carbon footprint approach, only twice reported previously in the wine sector, on one occasion without presenting inventory data (Penela, et al., 2009) and the other from a single vineyard in Italy (Marras, S., et al., 2015). This is a very convenient approach to push SME companies towards Eco-innovation and sustainability because it is easier for them to understand and apply.

Room for Eco-innovation has been found, as inventory data presented here will enable wineries to compare their own data with the average presented and to identify the most relevant aspects to their carbon footprint, as well as, potential improvements.

The main drawbacks and limitations of the study are the systematic truncation errors due to the bottom-up process approach and the limited number of indirect GHG emissions (scope 3 categories) included.

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