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Product vs Corporate carbon footprint: some methodological issues. A case study and review on the wine sector.

Alejandra Navarro[1, 2], *Rita Puig*[1], *Pere Fullana-i-Palmer*[3, 2]

[1] GIR, Escola d'Enginyeria d'Igualada (EEI), Universitat Politècnica de Catalunya (UPC, Barcelona tech), Pla de la Massa, 8, 08700 Igualada, Spain.
[2] Cyclus Vitae Solutions, S.L., Avinguda Caresmar 33, 1; 08700 Igualada, Spain
[3] UNESCO Chair in Life Cycle and Climate Change, School of International Business (ESCI-UPF), Pg. Pujades 1, 08003 Barcelona, Spain.

*Corresponding author: Rita Puig, Tel.:+34938035300; Fax:+34938031589. E-mail address: rita.puig@eei.upc.edu

ABSTRACT

Carbon footprint (CF) is nowadays one of the most widely used environmental indicators. The scope of the CF assessment could be corporate (when all production processes of a company are evaluated, together with upstream and downstream processes following a life cycle approach) or product (when one of the products is evaluated throughout its life cycle). Our hypothesis was that usually product CF studies (PCF) collect corporate data, because it is easier for companies to obtain them than product data. Six main methodological issues to take into account when collecting corporate data to be used for PCF studies were postulated and discussed in the present paper: fugitive emissions, credits from waste recycling, use of "equivalent factors", reference flow definition, accumulation and allocation of corporate values to minor products.

A big project with 18 wineries, being wine one of the most important agri-food products assessed through CF methodologies, was used to study and to exemplify these 6 methodological issues.

One of the main conclusions was that indeed, it is possible to collect corporate inventory data in a per year basis to perform a PCF, but having in mind the 6 methodological issues described here. In the literature, most of the papers are presenting their results as a PCF, while they collected company data and obtained, in fact, a "key performance indicator" (ie., CO_2eq emissions per unit of product produced), which is then used as a product environmental impact figure.

The methodology discussed in this paper for the wine case study is widely applicable to any other product or industrial activity.

Key words: life cycle assessment (LCA), key performance indicators, reference flow, environmental credits, vineyard, winery

1. Introduction

1.1. LCA based carbon footprint methodologies

There is a huge ongoing effort to improve and promote the use of life cycle assessment (LCA) in Europe, through the PEF[1] and OEF[2] methodologies, within the Single Market of Green Products Initiative[3]. Application of this methodology in a great variety of industries, such as agri-food (Iribarren, et al., 2011; Fantin, et al., 2014; Rinaldi, et al., 2014), waste management (Biganzoli, et al., 2015; Ioannou-Ttofa, et al., 2016; Styles, et al., 2016) and energy supply (López-Sabirón, et al., 2014; Gallejones, et al., 2015) among others, can be found in the literature. 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 a 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; such as the accounting of organic carbon (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 and 2011).

Corporate carbon footprint (CCF) can be calculated with three scopes (GHG corporate protocols, 2004 and 2011): 1) direct emissions, 2) indirect emissions from electricity production and other services, and 3) indirect emissions upstream and/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 (DIRECTIVE 2003/87/EC) and the dominant scopes are 1 and 2. The rest of the economic sectors have diffuse emissions and they are mainly found within scope 3. In order to calculate any contribution (the so-called emission factors in carbon footprint terminology) from a process within scope 3, such as the emissions 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 product carbon footprint (PCF) or a scope 3 CCF is at stage, there is somehow a need for LCA methodology. LCA is generally performed in a process-oriented approach, a "bottom-up" approach which needs to build the supply chain of the process and get data from each process unit.

The process-oriented approach is not the only one used to evaluate the environmental impacts of a product, due to the difficulties to get data from companies in the value chain, the time needed to perform such LCA studies and possible truncation errors (Lenzen, 2000), other approaches are described in the literature derived from the Environmental Input-Output (EIO) methodology based on financial accounts (Huang et al., 2009; Penela et al., 2009; Cagiao et al., 2011; Alvarez et al., 2014; Kjaer et al., 2015; Alvarez and Rubio, 2015; Alvarez et al, 2015). The hybrid approach (using both process-LCA and EIO methodologies) is a "top down" approach in which inventories are quantified using monetary data at a high aggregation level, and hybridized with "bottom-up" process-based data collection, when more detail is needed (Berners-Lee, et al., 2011). The advantage of such an approach is the use of readily available financial data as starting point for screening. For CCF, yearly financial

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

accounts together with supplier invoices provide the data input. For PCF, life cycle costing (LCC) inventories are needed.

Nevertheless, some uncertainties are still described within this "top-down" approach (Kjaer et al., 2015), and they are related to the EIO model used or the data inputs. On the one hand, model related uncertainties are mainly: data age (monetary data is unstable and vary over time), geographic coverage (data availability is higher from some geographic areas than others in the world) and sector aggregation (match between the category where money is spent and the EIO sector found in the databases; ie., a very specific spend, a "coffee machine" for example, doesn't match well with a wide EIO sector, as "machinery and equipment"). On the other hand, data uncertainty arises when changes are implemented, because it is important for companies to be able to monitor the effect of these changes. So this approach is useful for screening studies, but needs further development for more accurate and specific results.

Although both approaches, process-LCA and hybrid EIO-LCA, have the ability to assess both corporate and PCF by first calculating a detailed CCF and then distribute the GHG emissions among the products and services dispatched to the market, only the hybridized approach claims to do it (Alvarez and Rubio, 2015).

There is a lot of literature on carbon footprint calculations of products and companies, most of them using the process-LCA approach. When a PCF is performed, inventory data of all processes related to the production of this specific product should be collected. Nevertheless, due to the fact that, for most companies, it is easier to report global annual consumptions and emissions instead of the product's specific inputs and outputs, our hypothesis is that some PCF calculations are performed distributing the company's inventory data among the different produced products. Most of the literature on PCF doesn't explain in detail the type of inventory data collected.

The aim of this paper is, first of all, to show some methodological issues which have to be taken into account when following the previous described procedure when calculating a PCF (company's annual consumption distributed among the different produced products) and, secondly, to perform a mapping of the wine CF literature, as an example, to see how these methodological issues are treated.

1.2. Carbon footprint in the wine sector

Wine production constitutes one of the most ancient economic sectors, being still nowadays a very important agri-food activity in Europe. Grape growing, similarly to other agricultural activities, has a significant impact on the environment due to the use of fertilizers, pesticides, water and energy and due to soil erosion and land use.

In this context, many publications assessing the different environmental burdens associated with wine production for improvement can be found in the literature (Rugani et al., 2013; Bonamente, et al., 2016). Wine LCA studies vary on the type of wine, white (Fusi et al., 2014) or red (Gazulla et al., 2010; Pattara et al., 2012; Amienyo et al., 2014); the country where wine is produced, such as Spain (Gazulla et al., 2010; Vázquez-Rowe et al., 2012a; 2012b; Meneses, et al., 2016), 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; Meneses, et al., 2016) or cradle to gate (Pattara et al., 2012).

Many other published studies tackle only the CF of wine production systems, either PCF (Cholette et al., 2009; Pattara et al., 2012; Vazquez-Rowe et al., 2013) or CCF: one vineyard in Italy (Marras, S., et al., 2015) and a winery in Spain with no inventory data (Penela et al., 2009).

Wine LCA-related publications presenting inventory data (see Table 7) will be reviewed according to the above mentioned aim of the present paper. In addition, the authors have worked with 18 wineries within two research projects on CCF of the wine sector (CO2vino, 2014 and Vineco, 2014) and this experience will be used to show examples of the methodological issues described.

Three research questions were formulated with the aim of finding answers from our experience in CF projects of wine sector and after reviewing the above mentioned published literature:

1) Which are the problems we would face when collecting CCF inventory data to perform a PCF study?
2) Which is the usual procedure/approach of the published literature for the case study of wine?
3) Is it sensible/accurate to collect CCF inventory data to perform a PCF calculation?

Our hypothesis is that the gathered data is usually corporate data, because it is more easily obtained and can be more easily checked or audited. We want to discuss the possible deviations when performing this approach.

2. Materials and methods

In this paper the three research questions will be answered by combining 3 sources of information:

- The standards describing the methodologies to perform a corporate and a product CF.
- The authors' experience in the wine sector coming from two research projects studying 18 wine companies.
- The LCA literature for the wine sector published in scientific-international-peer-reviewed journals.

2.1. Standard methodology description for CCF and for PCF

Figure 1 illustrates the difference among LCA, PCF and CCF and more precisely between a CCF with only scope 1 (direct emissions) included, a corporate with all scopes included (1, 2 and 3, with direct and indirect emissions up and downstream) and a PCF. LCA is an environmental evaluation of a product along its life cycle, which includes many impact categories. On the other hand, carbon footprint calculations include only one impact category: global warming potential (see Figure 1). Between corporate and product CF the main difference is that one company can produce many products and when performing a CCF all the products of the company are included in the assessment, while in PCF only one product is evaluated (as shown in Figure 1). Additionally, a CCF may include scopes 1, 2 and 3, so that the whole life cycle is studied (upstream and downstream of the company), while scope 1 includes only direct emissions (the ones that take place within the company) (also shown in Figure 1).

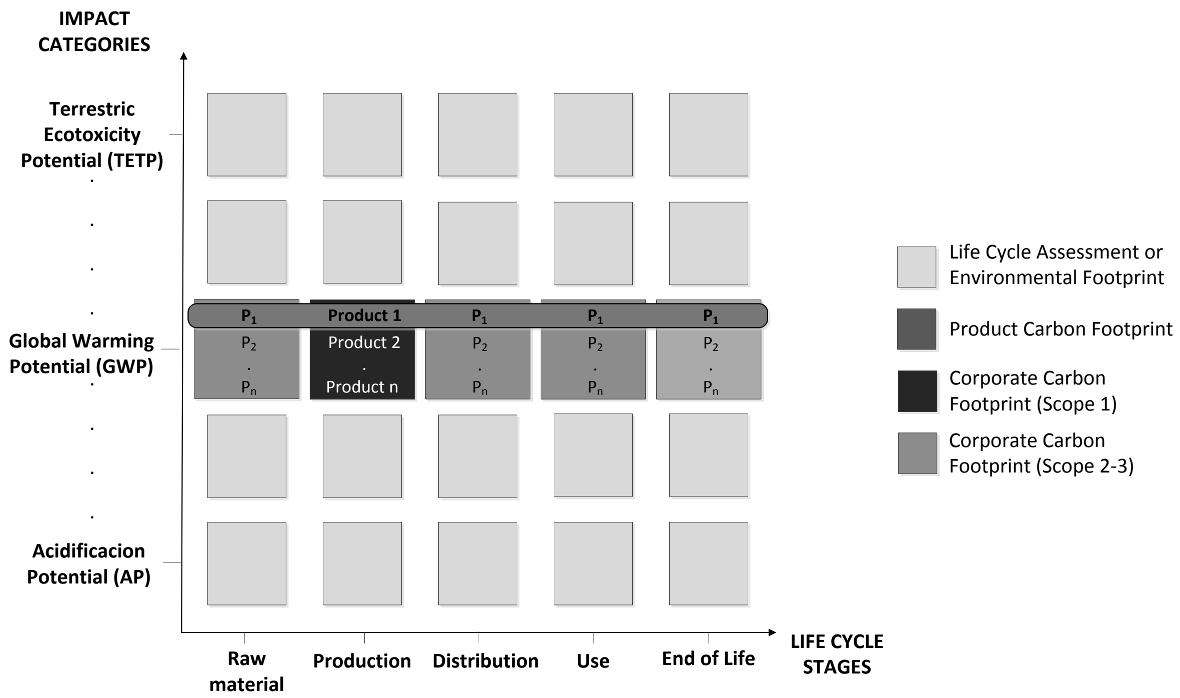

Figure 1. Differences between Life Cycle Assessment vs Corporate and Product Carbon Footprint (after Fullana-i-Palmer and Raugei, 2013).

CCF studies can include both, direct and indirect GHG emissions to help companies understand their whole value chain emissions impact in order to focus company efforts on the greatest GHG reduction opportunities, leading to more sustainable decisions about companies' activities and the products they buy, sell, and produce. Table 1 shows the detailed aspects included in each of the 3 scopes that a company can study in its CCF. Thus, for example, in scope 1 the emissions coming from combustion facilities (boilers, furnaces, etc.) have to be included, together with mobile combustions (from owned vehicles), fugitive emissions (from air conditioning and refrigerating facilities) and other physicochemical processes (such as waste water treatment plants owned by the company). Scope 2 includes the emissions due to the production of the electricity consumed by the company. As these emissions take place outside the company (in other companies producing electricity, like power-plants or nuclear-plants among others), they are considered indirect emissions. Other indirect emissions are included in scope 3, like the emissions due to the production of raw materials (category 1) consumed by the reporting company, or the treatment of its wastes (category 5 of upstream indirect emissions, Table 1).

Scope 1 and 2 are mandatory to include in any CCF reporting, while the inclusion of scope 3 is optional.

Table 1. CCF: emissions included in each scope. (Elaborated from GHG protocols corporate, 2004 and 2011)

Scopes		Items/Categories	Comments
1	Direct emissions	Stationary combustion	Emissions from combustion in owned or controlled boilers, furnaces, etc.
		Mobile combustion	Emissions from combustion in owned trucks, cars, etc.
		Fugitive emissions	Emissions from intentional or unintentional

			releases, e.g., equipment leaks from joints, methane emissions from coal mines and venting, hydrofluorocarbon (HFC) emissions during the use of refrigeration and air conditioning equipment and methane leakages from gas transport.
		Physicochemical processes	Emissions from manufacture or processing of chemicals and materials
2	Indirect emissions	Generation of purchased electricity	Emissions from the generation of purchased electricity consumed by the company
3	Upstream Indirect emissions	1. Purchased goods and services	Extraction, production, and transportation of goods and services purchased by the company
		2. Capital goods	Extraction, production, and transportation of capital goods acquired by the company
		3. Fuel- and energy-related activities (not included in scope 1 or scope 2)	Extraction, production, and transportation of fuels and energy purchased
		4. Upstream transportation and distribution	Transportation of products purchased by the company
		5. Waste generated in operations	Disposal and treatment of waste generated
		6. Business travel	Transportation of employees for business-related activities
		7. Employee commuting	Transportation of employees between their homes and their worksites
		8. Upstream leased assets	Operation of assets leased by the company
	Downstream Indirect emissions	9. Downstream transportation and distribution	Transportation and distribution of products sold by the company
		10. Processing of sold products	Processing of intermediate products sold
		11. Use of sold products	End use of goods and services sold by the reporting company
		12. End-of-life treatment of sold products	Waste disposal and treatment of products sold by the company
		13. Downstream leased assets	Operation of assets owned by the reporting company
		14. Franchises	Operation of franchises
		15. Investments	Operation of investments

The final report of a CCF contains the amount of CO_2eq emitted by the reporting company during the reported year. This account is very useful to identify where the largest energy, material and resource use takes place within the supply chain, in order to help decisions to reduce GHG emissions and to lead the company into a more sustainable business model. When the company begins to implement improvement measures, it is necessary to quantify the improvement achieved. This is why the “key performance indicators” are very useful to show the improvement evolution of the company throughout the years. These “key performance indicators” are calculated by referring the GHG emissions calculated per year in relation to the production (or the incomes, etc.) achieved in the same year. Thus, for example, when calculating the GHG emissions from a winery during one year, the result will be expressed in number of tones of CO_2eq emitted in 2014, while a “key performance indicator” could be defined as number of kg of CO_2eq emitted per bottle of wine produced, permitting then to compare 2014 emissions, with 2015 ones and so on. Is this key performance indicator equal to the PCF of a bottle of wine produced by that company? Not exactly.

PCF studies are meant to obtain the GHG emissions due to the life cycle of the product. An organization may wish to publicly communicate a PCF for many reasons which may include: providing information to consumers and others for decision-making purposes; enhancing climate change awareness; supporting an organization's commitment to tackling climate change; supporting implementation of policies on climate change management, etc. PCF quantification requirements are linked to communication aims (including intended target groups) and to verification.

The results of a PCF calculation will most probably be given in kg of CO_2eq emissions per unit of product. Although CF quantification result can be expressed in a very similar way between corporate (with "key performance indicators") and product approach, the inventory data needed in each case can vary significantly. Nevertheless, this aspect is not always reported in the literature.

Within the "wine family" many different products can be found, varying from red to white wine, with different production processes, types of packaging, grape varieties, etc. If the aim of the study is to obtain average statistical data on GHG emissions for the wine sector in a country in order to improve the environmental performance of this production sector, the expected result should be also expressed as kg of CO_2eq emissions per unit of average product (to allow benchmarking) and data will need to be gathered from the most representative wineries in the country. In this case, which approach and which data should be gathered: product or corporate data?

Six main methodological issues (differences between CCF and PCF), identified from the knowledge of both standards and from the experience elaborating product and corporate studies, are postulated and will be discussed and illustrated in the present paper:

a) Fugitive emissions: CCF includes fugitive emissions (ie. refrigerant gases) in scope 1, while PCF doesn't specifically mention them and might not be included if they are not part of the production process.
b) Waste: CCF doesn't include credits from the recycling of waste, in contrast to PCF.
c) Use of equivalent factors: they can be more precisely obtained in PCF than in CCF.
d) Reference flow definition: is the reference unit to which inventory data will be related. It means that consumptions per reference flow will be gathered (ie. in a wastewater treatment process all consumptions/emissions will be related to kg or m^3 of wastewater treated). Usually a correct reference flow definition is more important in PCF than in CCF, but not always.
e) Accumulation: can be a misleading factor in CCF but, usually, it wouldn't affect PCF.
f) Allocation to minority products: can be a problem in PCF, but not in CCF.

2.2. Case study of wine

To discuss the methodological issues postulated before (research questions to be answered) two main sources of information will be used: the experience of the authors coming from previous projects studying 18 wineries and a literature review of wine-LCA&CF related papers.

a) Literature review, source: published papers about LCA or CF of wine will be studied, with special emphasis on data collection and other details related with the previously indicated differences between CCF and PCF (such as refrigerant gases emissions, waste, reference flow, accumulation, etc.). Only papers presenting inventory data will be analysed.

b) Authors experience in wine projects: A total of 18 wineries were studied and average results were published (Navarro, et al., 2017). The reference unit for all our studies was defined as the production of a 0.75 L bottle of wine (obtained from processing 1 kg of grape). This can be considered as the functional unit (FU) for PCF studies, because their usual aim is to determine the hotspots in the life cycle of the product. Nevertheless, in CCF studies there is no functional unit, only key performance indicators to relate the impact to the production of the company. Inventory corporate data was gathered through questionnaires and meetings with company-responsible persons of the participating wineries. System boundaries of the study are shown in Figure 2. Vineyard subsystem includes all agricultural operations needed for grape growing and final harvesting to obtain the grapes, which are the input to the winery subsystem. The winery subsystem includes wine production, bottling and packaging processes.

Methodological issues postulated before will be illustrated with examples coming from the authors' experience with those wineries.

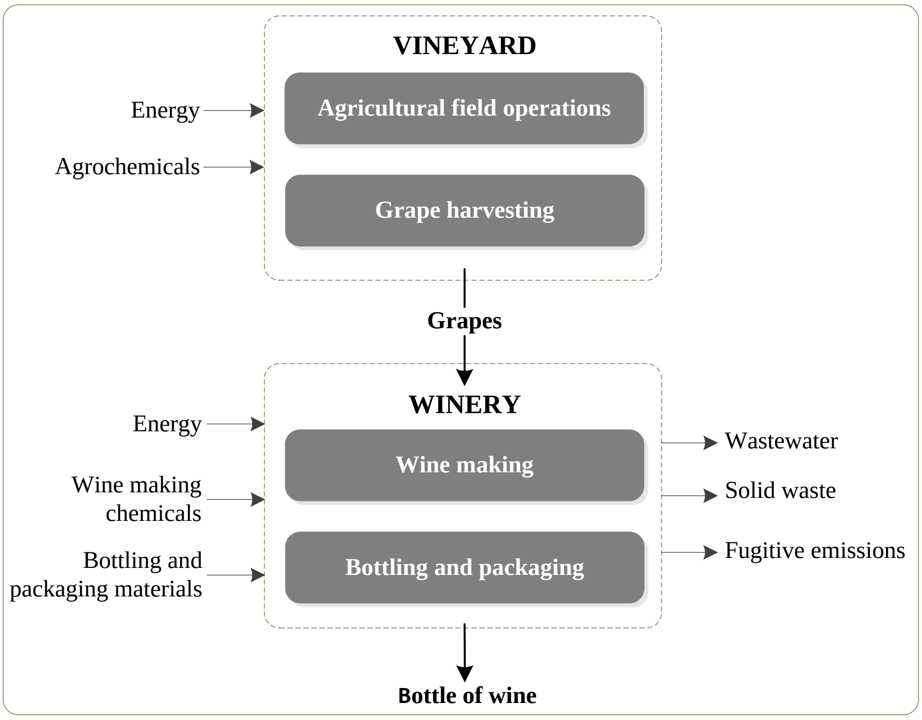

Figure 2. System boundary and flow diagram of the wine production system.

It is important to say that, although grape variety, climate and technologies of winemaking are important issues that deserve further analysis and of course affect the CF results of any wine, it is not the aim of this paper to explain and detail the different grape varieties and technologies used by the wineries studied. The most important phases of winemaking are (Zeppa, 2007): must production, alcoholic fermentation and bottling. Must production and fermentation technologies are different for white and red wines and there are also differences among wines in the same category. For white wine, grape crushing must be done very carefully because the compounds present in the skin and stem must not pass into the must (thus, it is obtained with a simple grape pressing). On the contrary, in the must used for red wine production, skins and seeds are present and during the alcoholic fermentation the color and tannin must be extracted. Another difference is that, during alcoholic fermentation, selected yeasts, sulfur dioxide and nutrient substances are added. Type and quantities of yeasts and nutrients depend on the type of grape and wine to be produced. All these inputs affect the CF calculation.

Therefore, the CF result for a winery is an indicator, which evaluates the performance of this specific winery and its evolution along the time. CF results should not be used to compare wineries or wines, because, as mentioned before, there are many issues affecting these results.

3. Results and Discussion

3.1. Average CCF results: from our case study on wine

Carbon footprint calculations, from vineyard and winery inventory data (Figure 2), 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, waste treatment, etc., emission factors were obtained from IPCC 2007 (IPCC 2007a; IPCC 2007b). They were calculated according to country and region specific characteristics.

The overall average CCF of the 18 wineries studied delivered, as key performance indicator: 0.85 kg CO_2-eq per one bottle of 0.75L of wine (see Table 2) (Navarro, et al., 2017).

Table 2 Contribution of each wine production process to the carbon footprint of 0.75 L of wine.

	Average [kg CO_2-eq/bottle]
Vineyard phase	*0.23*
Winery phase	*0.62*
Total bottle 0.75 L wine	**0.85**

3.2. Discussion of methodological issues (differences between CCF and PCF) with examples

3.2.1. Fugitive emissions

CCF includes fugitive emissions (from intentional or unintentional releases, e.g., hydrofluorocarbon (HFC) emissions during the use of refrigeration and air conditioning equipment) in scope 1, while product carbon footprint doesn't specify it and, probably, for many products, if these fugitive emissions are not directly related to the product production process, they will not be considered. This is the case of release of refrigerant gases in winery, not directly related with the production process of wine. In this case study, the difference of considering or not considering the refrigerant gases release is not significant (about 0.2%, see Figure 3) but, it might be more important for other types of products.

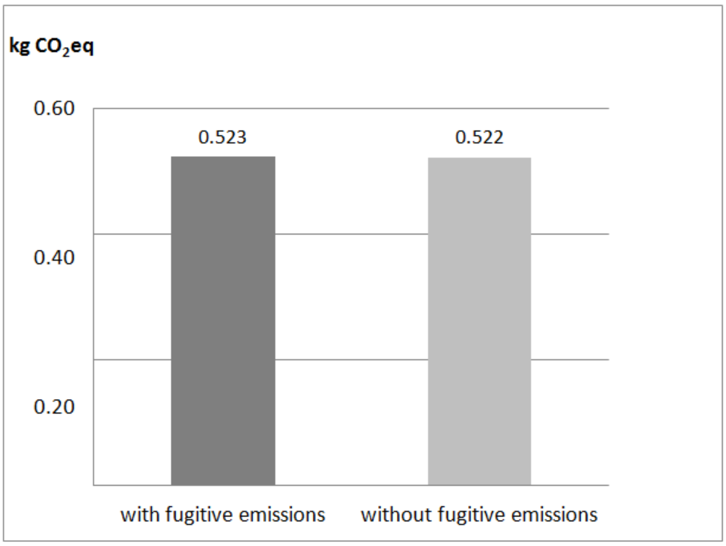

Figure 3. Carbon footprint (kg CO_2 eq/bottle) of the same winery by considering and not-considering the refrigerant gases fugitive emissions.

3.2.2. Environmental credits from waste recycling

The calculation of CO_2eq emissions due to the production and treatment of waste is different between CCF and PCF. Scope 3 of CCF includes a category named "waste generated in operations". To calculate the CO_2eq emissions within this category, two types of wastes are distinguished: the ones going to a recycling process, in which case only transport to the recycling facility is considered (not the recycling process itself), and the ones going to landfilling or other final treatments, where both transport and treatment burdens are allocated to the producer. According to the Corporate scope 3 GHG protocol (GHG Protocol, 2011), to avoid double counting of emissions from recycling processes by the same company, companies should account for upstream emissions from recycling processes in category 1 and category 2 (see Table 1) when the company purchases goods or materials with recycled content. In category 5 and category 12, companies should account for emissions from transport and final treatments, but should not account for emissions from recycling processes themselves (these are instead included in category 1 and category 2 by purchasers of recycled materials). Companies should not report negative or avoided emissions associated with recycling in category 5or category 12 (see Table 1). Any claims of avoided emissions associated with recycling should not be included in, or deducted from, the scope 3 inventory, but may instead be reported separately from scope 1, scope 2, and scope 3 emissions.

In PCF calculations wastes going to recycling and/or recovery are considered as part of the system studied and burdens from both, transport and recycling treatment, are considered in the calculation and also credits are obtained by the studied product/service from the recovered/recycled material produced, because it will substitute the corresponding amount of virgin material in the same or other product system. Thus, according to ISO 14067, there are two procedures to treat recycling in PCF studies: the closed-loop allocation procedure and the open-loop allocation. Closed-loop allocation can be applied to closed-loop systems (the recycled material is used in the same product system again) and to open-loop systems when the recycled material has the same inherent properties as the primary material. In those cases, GHGs emissions of recycling process are allocated to the product that delivers the recycled material and this recycled material (which leaves the product system) carries a "recycling credit" which corresponds to the GHGs emissions of the primary material acquisition.

If an open-loop recycling takes place, in which the material is recycled into other product systems and undergoes a change to its inherent properties, allocation procedures are needed (ISO 14067, 2013). In this case, the "shared unit processes" are the extraction and processing of raw materials, the collection and recycling processes, and the end-of-life operations. The percentage of this shared unit processes that corresponds to the product studied and to the other product systems have to be justified. Further guidance should be found in sector guidance and published product category rules. For instance, a closed-loop recycling would be a company producing plastic components which re-uses its own plastic waste in the same production process, while if plastic waste goes to another company to be recycled, then it is an open-loop recycling. In open-loop recycling, if the recycled plastic has the same quality than before, then the recycled process together with the credits from the new plastic obtained are allocated to the first product. Nevertheless, if the recycled plastic has lower quality, allocation of impacts to the first and second products has to be justified (Bala et al, 2015).

For example, when the winery produces glass waste (due to some bottles that were accidentally broken) an open-loop recycling takes place. In this case, the CCF methodology would only consider the transport of the glass waste from the winery to the recycling plant as part of the studied system, while the PCF would consider also the recycling treatment and the credits for the recycled glass obtained (which will avoid a certain quantity of virgin glass to be produced). One of the studied wineries (producing 596500 L of wine in 2013) reported 200 kg of glass waste. In this specific case, although methodologically important (and probably quantitatively relevant for other sectors), the difference between both approaches (corporate vs product in the wine sector) due to glass recycling was very small, only about 0.018% (see Table 3).

Table 3. Comparison between corporate and product approach in relation with the treatment of recycled waste.

Life Cycle stage	CCF (No credits from recycled waste) [kg CO_2 eq/bottle]	PCF (With credits from recycled waste) [kg CO_2 eq/bottle]	Credits from glass recycled [kg CO_2 eq/bottle]
Vineyard	1.195	1.195	0
Winery	0.505	0.5046	$-3.07*10^{-4}$
Total	1.7	1.7	$-3.07*10^{-4}$

3.2.3. The influence of using "equivalent factors"

Equivalent factors are used when a mixture of products is studied. For example, in the wine sector, when a winery cooperative resulting from the association of many farmers is producing different types of wine, an average yield from grapes to wine has to be taken. In our study, the factor used was 1kg of grape = 0.75 L wine. This figure came from wineries involved in the project. If this factor is slightly different, the results of carbon footprint are strongly affected (see Figure 4). This equivalent factor usually varies between 1 and 1.2 kg grape/L of wine; although a minimum value of 0.9 and a maximum of 1.7 has been found in the literature (see Table 7). This uncertainty, in our results, gives a 20% increase in the contribution of the vineyard phase and a 5.4% increase in the CF of one bottle of wine.

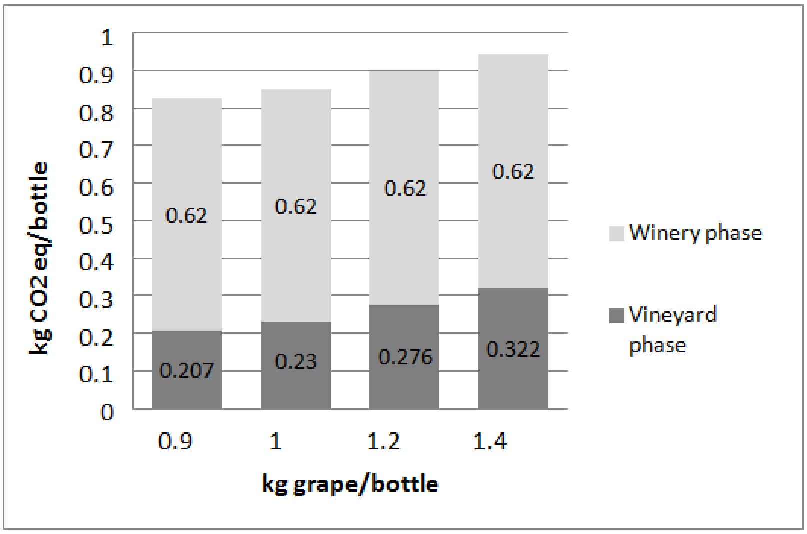

Figure 4. Carbon footprint results per bottle of wine: contribution of vineyard phase depending on the "equivalent factor" considered.

3.2.4. Importance of the reference flow definition

When calculating the CCF or PCF within a company which has processes in different locations and the connection of the processes could be made with different reference flows, it is important to choose the most convenient one, because this choice can deeply affect the results of the calculations.

In the case of the wine sector, this issue is shown when connecting the vineyard stage (agriculture) with the winery (industry), because the process data from the vineyard stage can be obtained per ha cultivated or per kg of grape collected, and then the ha or the kg of grape have to be related to the amount of wine produced. In this case, as a whole, results show a wider variation, in inventory data average, if ha is used as the reference flow, while kg of grapes is a more stable choice (see coefficient of variation, CV, in Table 4). This aspect was more deeply discussed in a previous paper (Navarro, et al., 2017).

When the inventory data is used to calculate impact results, thus the CCF impact result of the vineyard, the "key indicator" kg CO2eq emitted per kg of grape produced, is different if kg of grapes is used as the reference flow compared with using the cultivated area in ha (see Figure 5). In this last case, an additional "equivalent factor" to convert ha into kg of grapes was used (coming from vineyards participating in the project): it was assumed that, in average, 0.0002 ha produce 1kg of grape.

Table 4. Inventory data of vineyard phase per kg of grape or per ha.

Vineyard phase Inputs	CASE 1: Per kg of grape					CASE 2: Per ha of vineyard				
	Min.	**Max.**	**Mean**	**SD.**[c]	**CV.**[d]	**Min.**	**Max.**	**Mean**	**SD.**[c]	**CV.**[d]
Organic fertilizer [kg N][a]	0.00003	0.0102	0.0048	± 0.0037	77%	0.1	61.0	29.9	± 26.7	89%
Urea based synthetic fertilizer [kg N][a]	0.0020	0.0060	0.0037	± 0.0019	53%	9.9	46.0	30.9	± 17.4	56%
Phosphorous based synthetic fertilizer [kg P2O5][b]	0.0036	0.0357	0.0114	± 0.0137	121%	20.0	213.7	70.1	± 51.7	116 %
Phytosanitary products	0.0026	0.0224	0.0081	± 0.0074	91%	12.3	189.9	52.3	± 81.6	99%
Diesel [L]	0.0120	0.0611	0.0310	± 0.0150	48%	44.6	474.8	221.2	± 144	65%
Electricity [kWh]	0.0009	0.0770	0.0450	± 0.0280	62%	10.0	568.0	352.4	± 207	59%

[a] Values were expressed in kg of nitrogen (N) content of each fertilizer product.

[b] Values were expressed in kg of phosphorus pentoxide (P2O5) content of each fertilizer product

[c] SD: Sample Standard Deviation:

$$\mathrm{SD} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2}$$

[d] CV: Coefficient of Variation:

$$\mathrm{CV}(\%) = 100 \times \frac{\mathrm{SD}}{\mathrm{Mean}}$$

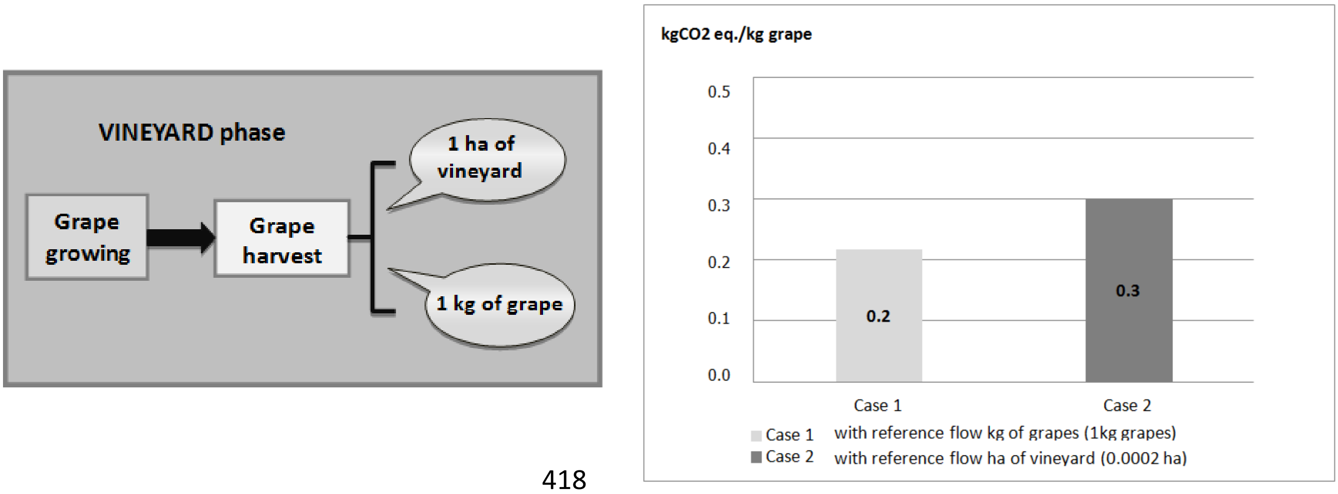

Figure 5. Impact results of vineyard CF per kg of grape depending on the reference flow

3.2.5.Accumulation

When collecting corporate data from a company, some inconsistencies may appear due to accumulation. To prevent this, when inventory data is gathered through a questionnaire, additional cross-check information should be asked.

For example, in our case study a winery reported for 2013 the amount of bottled wine produced (8119827 L), the total weight of glass bottles bought (874643.7 kg) and the average weight per bottle of 0.75L of wine (0.41-0.54 kg/bottle). With this information, if the average weight per bottle is calculated by dividing the total weight of glass bottles bought by the number of bottles (0.75L wine), an average of 0.081 kg/bottle is obtained (far below the range reported). When asking the winery for this inconsistency, it was found that stored bottles from previous years were used and part of the wine produced was to be bottled during years to come (“crianza” wines). The conclusion is that, when checking the mass balance, accumulation may be very important for this sector and others, while usually only in and out of mass and energy is accounted, expecting that one year is a long enough period to avoid accumulation.

3.2.6.Allocation of company data to minor products

A company may sell different products. The calculation errors are higher when the amount of the studied product is lower in relation to the total amount of products manufactured by the company.

One of the studied wineries was a cooperative company with many vineyards providing grapes. The winery makes different types of wine (as shown in Table 5) and they wanted to calculate the PCF for their highest quality wine (Chardonnay white wine), which represented 0.037% of their total wine production. The winery has no specific data on production processes (vineyard and winery) for this specific wine, they only provided its specific packaging data and the area of vineyard and kg of grape from which this wine came from (see Table 6). All other inventory data was aggregated data from all wines produced and the corresponding part had to be allocated to this Chardonnay wine.

Table 5. Types of wine produced in the winery and winery allocation factor.

TYPE OF WINE		Quantity [L]	*Mass percentage [%]
Rosé (total)		336569	
White	White (total)	8692199	
	Chardonnay wine	**62602.5**	**0.37 %**
Red (total)		7694649	
TOTAL wine production		**16723417**	**100 %**

**Quantity of specific wine related to the total production in %.*

Table 6. Vineyard allocation factors for the Chardonnay wine under study.

	Vineyard area [ha]	% of area	Quantity of grape [kg]	% of grape
Chardonnay wine under study	**29.1382**	**1.2**	**101620**	**0.46**
TOTAL wine produced	2462.34		*22297889	

**Value calculated from the total wine produced (L), reported by the winery, after considering that 1kg grape = 0.75L wine*

In the absence of the specific inventory data for the product (Chardonnay wine), the allocation of a fraction of the total consumption of pesticides, fuels, oenological products, etc., used by the winery and their farms during the campaign 2013 was needed. For the vineyard inputs, the allocation factor used was 0.46% (obtained from the relation in kg of grape). For the winery consumptions the allocation factor was 0.37% (calculated regarding L of wine).

It was noted that this allocation had a very important role in the result. For example, if the allocation of vineyard phase was carried out based on the hectares occupied by Chardonnay wine (1.2%) related to the total vineyard area (one may think that the application of pesticides and fertilizers may depend more on hectares than on kg) instead of kg of grapes (0.46%), the result of carbon footprint would have been 4.1 kg CO2 -eq per bottle, very different from the 1.97 kg CO2-eq per bottle obtained and away enough from the values found in the literature (usually between 1 and 2 kg CO2-eq per bottle). According to our results (Navarro, et al., 2017) taking "kg of grape" as the reference flow for vineyard phase is more accurate than taking "cultivated area". As discussed in section 3.2.4, this second choice has a higher standard deviation.

Usually, the lower the representativeness of the wine product to assess respect to the total production of wine from the cellar, the greater the mathematical error generated by the allocation procedure.

3.3. *Methodological choices found in LCA/CF literature about wine*

In Table 7, wine literature showing inventory data and CF or LCA impact results is evaluated according to methodological issues described in the previous section.

Table 7. Details on wine LCA and CF studies reported in the literature.

Wine literature LCA & CF	Wine FU[a] Vineyard RF[b]	Inventory data		Nº of companies	Credits from waste? [c]	Comments
		vineyard	winery			
Amienyo et al., 2014 Product LCA	1 bottle of wine (0.75 L) 1 ha	✔	✔	1 winery Australia	NO; burdens of recycling goes to the user of recycled material together with credits from avoidance of virgin material	• 1 type of red wine • 10 t of grape produced/ha • 1.05 kg grape = 0.75 L wine • 0.86 kg CO2 eq/ bottle (cradle to gate)
Ardente, F, 2006. Product LCA	1 bottle of wine (0.75 L) 1 ha	✔	✔	1 winery Italy	NS	• 6 types of wine • 1 kg grape = 0.75L wine • 1.6 kg CO2 eq/bottle • 3 indicators: energy consumption, CO2 emissions, and water consumption.
Bellon-Maurel, V., et al., 2015 Product LCA	1 kg grape (Syrah) 1 year (2006)	✔		1 vineyard France	NO cred from waste	• Aiming at simplifying collection of inventory data in agricultural works • Different plots (soil properties) • Vineyard: 0.16 – 1.39 kg CO2/kg grape

Benedetto, G., 2013. Product LCA	1 bottle of wine (0.75 L) 1 ha	✔	✔	1 winery Italy	NS	• 1 type of wine from a winery producing various • 1.39 m^2 =1.67 kg grape=1L wine • 1.64 kg CO_2/bottle
Bosco et al., 2011 Product LCA (PEF)	1 bottle of wine (0.75 L) NS (follows EPD 2008)	✔	✔	4 wineries Italy	YES; allocation of impacts to by-products and wastes (fertilizers, etc.)	• 4 types of wine • 0.6-1.3 kg CO_2 eq/bottle (includes distribution & waste management) • Agriculture responsible for 20% of CF
Fusi et al., 2014 Product LCA	1 bottle white wine (0.75 L) 1 m^2	✔	✔	1 winery Italy	NS; although they consider glass recycling rates higher and lower than the 61% considered as input	• Year 2012 • 1 type of wine • 1 m^2 vineyard = 1.071 kg grape = 0.75 L wine • Vineyard 0.17 kg CO_2 eq/bottle and winery 0.83 kg CO_2 eq/bottle
Gazulla et al., 2010 Product LCA	1 bottle of wine (0.75 L) 0.0002 ha	✔	✔	Some wineries Spain	YES	• Rioja “crianza” wine • 1.273 kg grape = 0.75 L wine • Vineyard 0.5 kg CO_2 eq/bottle and winery 0.43 kg CO_2 eq/bottle
Iannone et al., 2016 Product LCA	1 bottle of wine (0.75 L) 1 kg of grape		✔	1 winery Italy	NS; probably yes from recycling of glass	• 4 wines (red and white) • 1.078; 1.208; 1.36; 1.465 kg grape / bottle
Marras, S., et al., 2015 CCF	1 kg grape 1 ha	✔		1 vineyard Italy	NO	• CF result 0.39 kg CO_2 eq/ kg grape • Only scope1 • 1.1 kg grape = 0.75L wine
Neto et al., 2013 Product LCA	1 bottle of wine (0.75 L) NS	✔	✔	1 winery Portugal	NS; although waste is quantified	• 2008 • 1 type of wine • 1 kg grape = 0.75 L wine
Pattara et al., 2012 Corporate vs PCF	1 bottle of red wine (0.75 L)			1 winery Italy	YES; identifies credits from waste as a difference between corporate and PCF	• 2010 & 2011 • only impact results • comparison between CCF calculator and PCF • 70 t grape = 50,000 L wine • 1.29 kg CO_2 eq/bottle
Villanueva-Rey et al., 2014 Product LCA	1 bottle of wine (0.75 L) 1.1 kg grape	✔		3 wineries Spain	NO	• Different viticulture techniques • 2010 & 2011 • Use of land and labour impacts: methodology described
Point et al., 2012 Product	1 bottle of wine (0.75 L)	✔	✔	12 wineries Canada (Nova	NS	• 2006 • 1.25 kg grape = 0.75 L wine

LCA	1 ha			Scotia)		• representative for Nova Scotia • vineyard 0.80 kg CO2 eq/bottle and winery 0.81 kg CO2 eq/bottle
Thomas, M., 2011. Product LCA	1 bottle of wine (0.75 L) 1 ha	✔	✔	2 wineries New Zealand	NO; transport included but not benefits from recycling	• 1 type of wine (Sauvignon Blanc wine) • 1.04 kg grape = 0.75 L wine • Distribution included • 1.4 kg CO2 eq/bottle
Vázquez-Rowe et al., 2012a Product LCA	0.75 L white wine (Ribeiro) 1.1 kg of grapes	✔		40 vineyards Spain	NA	• 2007-2010 • 1.1 kg grape = 0.75 L white wine • LCA and DEA (Data Envelopment Analysis) • Comparing efficiency of vineyards • Vineyard 0.46 ± 0.2 kg CO2 eq/bottle
Vázquez-Rowe et al., 2012b Product LCA	1 bottle of wine (0.75 L) 1.1 kg grape	✔	✔	1 winery Spain	NO	• Ribeiro appellation white wine • 2007-2010 • 2.64 – 3.21 kg CO2 eq/bottle
Vázquez-Rowe et al., 2013 PCF	1 bottle of wine (0.75 L) 0.9-1.25 kg grape/bottle	✔	✔	4 Italy, 42 Spain, 2 Luxembourg wineries	NS	• 9 different types of wine • data from different literature sources • Vineyard 1.6 kg CO2 eq/bottle Ribeiro

[a]FU: functional unit of the study. [b]RF: reference flow. It refers to the unit used as reference for vineyard inputs and outputs (kg grape or ha cultivated). [c]NS: not specified; NA: not applicable.

Literature review shows clearly that, in all previous references, inventory data is obtained from each company (winery or vineyard) as corporate inventory for a specific year. In case that the company is producing a single wine, this corporate inventory is equivalent to a product inventory at the production stage, but if the company is producing several wines an average is obtained (implicitly allocating by mass). This fact demonstrates our first hypothesis: it is easier for companies to obtain corporate data than product data. Thus, the usual way to proceed is to collect corporate data and obtain a “key performance indicator” that is usually used as a product environmental impact figure. Apparently, none of the revised papers took into account the fugitive emissions of refrigerant gases, as it would have to be done in corporate carbon footprint accounting according to GHG Protocol (2004) and ISO 14064.

Some of the published studies are using the surface of cultivated vineyard as the reference flow in the agricultural stage (which, as said before, has a higher standard deviation), while others are using the kg of grapes produced.

There are also some of the studies that calculate the avoided impacts due to the recycling of wastes (ie. glass waste) and use them as environmental credits. Other papers don’t consider or don’t mention it.

Only one of the previous published studies states that the data of the winery is allocated to one of the various types of wine produced (Benedetto, G., 2013.), but it doesn't mention the representativeness of this specific wine within their global wine production.

Although the equivalent factor used from kg of grape to L of wine produced has a great influence on the results, none gives much importance to this factor and not all of them are mentioning the value used for this conversion (ie. Bosco et al., 2011). The amount of grape needed to produce 1 bottle (0.75 L) of wine is very variable, depending on the type of wine 0.9-1.465 kg grape/bottle. White wine usually needs more kg of grape than red wine. The most often reported value is 1.1 kg of grape per bottle of wine.

Finally, the CF-results-margin reported in this previous literature for a bottle of wine will be also summarized here, just for curiosity reasons. The total CF for a bottle of wine (vineyard+winery impact) varies from 0.6 to 3.2 kg CO_2 eq/bottle. The CF of the vineyard stage varies from 0.2 to 1.6 kg CO_2/bottle and, in the winery phase, from 0.43 to 0.83 kg CO_2 per bottle of wine. The reported weight per empty bottle varies between 202 g/bottle ("Chianti Colli Senesi" wine) and 571g/bottle (Vázquez-Rowe et al., 2013). The average results obtained in our case study (0.23 kg CO_2eq/kg grape and total CF value of 0.85 kg CO_2eq/bottle of wine) are within the range reported in these previous publications. These different results are normal because the wine-making process has different options (ie., for white wine compared to red wine, sparkling or non-sparkling wines, young or reserve wines, etc.). The vineyard phase is also different depending on the cultivated rape variety, the type of land and the climate conditions among others (ie, in areas with very humid weather more amount of fungicides have to be applied but less irrigation is needed). Therefore the CF results should not be used to compare wines or wineries, but to improve the environmental performance of a specific wine or winery along the time.

3.4. Application of the results to other industries

The six methodological issues identified and discussed here with examples from the wine case study are applicable to other companies, dealing with food or non-food products. The six topics identified as differences between corporate and product CF approaches (fugitive emissions, credits from waste recycling, use of "equivalent factors", reference flow definition, accumulation and allocation of corporate values to minor products) are general and could affect the CF results of any type of industry.

An example of these six methodological issues in the case of olive oil production is discussed here as another very similar example:

- Fugitive emissions: if there are air conditioning devices or cold storage rooms in the oil making company, their impact will be included in a CCF but probably not in a PCF.
- Credits from waste recycling: credits from the recycling of the glass from the olive oil bottle will be included in a PCF, but probably not in a CCF.
- Use of "equivalent factors". An important equivalent factor in this case is the amount of olive oil obtained from 1 kg of olives. This equivalent factor can be different depending on the type of olives, their maturity and the year studied. It is important to take the specific "equivalent factor" for each olive oil and avoid using averages.
- Reference flow definition: the production of olive oil has a first agricultural life cycle stage (similar to wine). In this case also, the use of ha or kg of olives as reference flow to quantify inputs and outputs from agriculture, will be probably an important issue.

- Accumulation: stocks of glass bottles or additives from last year would also affect the results of a product carbon footprint coming from corporate data.
- Finally, allocation of corporate data to minor products (ie. a very especial extra virgin olive oil) should be avoided.

It is important to notice that what is discussed here for corporate vs product CF approach, single indicator, can be extended to environmental footprint (EF) approach, multiple indicators. In the EU, there is an on-going effort now to develop category rules on how to perform product environmental footprints (PEF) and organization environmental footprints (OEF), following the same patterns as for CF. The category rules are meant to say what to consider and how to perform the LCA for a specific product category. The product category rules are a solution to harmonize product LCA studies, but they don't avoid the fact that inventory data is usually gathered as corporate data, therefore the methodological issues discussed here (comparing corporate vs product approaches) are still very relevant. PEF system follows a product approach and the category rules are not addressing subjects like fugitive emissions (because this is very specific for only carbon footprint), neither accumulation nor allocation of corporate values to minor products, etc.

The rules of PEF for leather (another very different product), for example (Fontanella, et al., 2016), don't address fugitive emissions (although most leather companies have cold storage rooms) , neither accumulation (although many chemicals are stored from year to year) nor allocation of corporate values to minor products. On the other hand, they are giving guidelines on how to address credits from waste recycling; the use of "equivalent factors" (ie. conversions from kg of hide to surface (m2) of final leather) and reference flow definition (ie. the number of animals needed to produce a specific amount of raw hide/skin).

Therefore, methodological issues already discussed here, between corporate and product CF, are still significant.

4. Conclusions

The main conclusion of this study is that, yes, it is possible and accurate enough to evaluate a PCF collecting corporate data. Nevertheless, the six methodological issues identified and discussed here have to be taken into account in every case study, because they could strongly affect the results. These 6 topics are: fugitive emissions, credits from waste recycling, use of "equivalent factors", reference flow definition, accumulation and allocation of corporate values to minor products.

From our case study on wine (two projects including 18 wineries), two of the previous topics (fugitive emissions and credits from waste recycling) showed very small influence in the results (0.2% and 0.02% respectively). On the contrary, the other four topics were identified as being very significant in this case study: a) "Equivalent factors": obtaining an accurate value of "kg of grapes needed to produce 0.75 mL of wine" was identified as being very important to get precise results; b) Reference flow definition: using kg of grape as reference flow for the vineyard phase leads to more accurate results than using cultivated area (in ha); c) Accumulation: stored glass-bottles from previous years would have lead to highly inaccurate results if it had not been detected; d) Allocation to minor products: using specific product data for minor products instead of allocating them the corporate data, is recommended.

The wine literature review (17 wine-LCA papers reporting inventory data together with CF results) lead to the conclusion that most of the papers are presenting their results as a "PCF", while they collected company data in a per year basis (CCF). This fact demonstrates our first hypothesis: it is easier for companies to obtain corporate data than product data. Thus, the usual way to proceed is to collect corporate data and obtain a "key performance indicator" that is usually used as a product environmental impact figure. Regarding the 6 topics previously described: the account of fugitive emissions from refrigerant gases was not reported in any of the published papers; most of the papers don't consider or don't mention credits from waste recycling; none of the published papers gives much importance to the "equivalent factor" kg of grape per wine-bottle and not all of them are mentioning the value used for this conversion (ie. Bosco et al., 2011); the reference flow used in the vineyard phase is not always the same: in some papers the vineyard cultivated-area was used while in others they use the kg of grape produced. Finally, only one of the published studies states that the data of the winery is allocated to one of the various types of wine produced (Benedetto, G., 2013.), but it doesn't mention the representativeness of this specific wine within their global wine production.

Being, nowadays, CF one of the most widely used environmental indicators, it is important that all stakeholders take into account the methodological aspects described here in order to obtain as much accurate results as possible.

Although product category rules are being developed in the EU for different products to harmonize the LCA studies and results to obtain a product environmental footprint (PEF), these rules are not usually addressing, not solving, the type of core-data (corporate or product) to be used in the study. A PEF study follows a product approach and what is discussed in the present paper is the comparison between product and corporate approaches. Therefore, methodological issues discussed here between corporate and product CF are still significant when comparing corporate and product environmental footprints (OEF vs PEF). This is why the present paper is very relevant.

Finally, some practical implications for companies arise from this study, the most important ones are that: 1) it is possible to collect corporate data to perform a product carbon footprint (or environmental footprint), but, when doing so, 2) a especial care of the 6 methodological issues described here is needed and details on how they have been addressed should be included in the report.

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