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Reduction of Carbon Dioxide Emissions during the Vinification Stages of a White Wine Produced in Italy

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In the last twenty years, the worldwide interest regarding environmental aspects has consistently increased. Despite the wine's industry has been always considered as environmentally safe, some research has shown that a large number of environmental concerns can be associated with the wine's production.
In this study, the environmental emissions, with particular reference to carbon dioxide, related to the vinification stages of a high quality white wine produced in Campania (Italy) were determined using a Life Cycle Assessment (LCA) analysis. An in-depth analysis was performed aimed at proposing alternative solutions that assess the reduction of environmental emissions of the more critical stages. The emissions to air were reported to the chosen functional unit (a 0.75 L bottle of wine). The study was performed, according to the international standards ISO 14040 and ISO 14044, using SimaPro 8.0.3 software and the Ecoinvent database.

1. Introduction

Carbon dioxide emissions reduction achieved a leading position in the last two decades research. Even if considered "not dirty" if compared to chemicals and mining industries, the food industry is a large user of energy and, therefore, largely contributes to total carbon dioxide emissions (Roy et al., 2009). Indeed, for the food sector, energy consumption was 27 million tonnes oil equivalent in 2009, or 10% of the total energy consumption of all industrial activity in Europe (LIFE13 ENV/ES/000280). Considering that consumers tend to approve with favour environmentally friendly products (Barber et al., 2009), industries, like the one of wine production, which environmental issues have been for years unexplored, became among the most studied ones (Rugani et al., 2013). This work concerns the environmental emissions of a high quality white wine produced in Campania (Italy) and exported in the whole country and in China; the environmental emissions, with particular reference to carbon dioxide, were determined using a Life Cycle Assessment (LCA) analysis. LCA is a well-established and ISO standardized analysis (according to ISO 14040 and ISO 14044) that has been used in the last years to quantify the environmental impacts of products, processes or services, using a "from cradle to grave" approach that allows to identify, quantify and evaluate all the resources consumed and the wastes released. To perform an LCA analysis of the production of wine, four main stages have to be taken into account: viticulture (related to vineyard planting and grapes cultivation), wine production and bottling (from vinification to storage), wine distribution and sales, and disposal of empty bottles. In the last years, various "from cradle to grave" LCA analyses have been performed. For example, Gazulla et al. (2010), starting from viticulture and grape growing phase, studied the life cycle stages of a Spanish red wine production, identifying the most critical ones. Bosco et al. (2011) made an LCA analysis on four high quality wines produced in the Maremma Italian district, including all the products' life cycle stages, with a special interest on the agricultural phase (including also the vineyard planting phase). Point et al. (2012) used an LCA analysis to quantify environmental impacts of a bottle of wine produced in Nova Scotia, Canada; they proposed alternative scenarios using lighter bottles or different transport modes and distances to reduce the environmental impacts of the most critical stages. Fusi et al. (2014) performed an attributional LCA to deepen the assessment of the environmental impacts of a Vermentino white wine produced in Sardinia, Italy and exported all over the world. Some studies, using a "from cradle to gate" or a "from gate to grave" approach were also performed. For

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example, some authors considered the distribution but not the waste disposal stages, like Ardente et al. (2006) that analysed the structure and activities of an Italian wine-producing firm, or Neto et al. (2013) that performed a LCA study for the vinho verde, a white wine produced in the northern part of Portugal. Other studies considered the waste disposal but not the distribution (Iannone et al., 2014); other did not consider neither the distribution nor the waste disposal step (Benedetto, 2013). When in the aims of the work there is a decisional support, a “gate to gate” approach with the deepening of a single step of the process, that can be, for example, the viticulture (Vázquez-Rowe et al., 2012) or the end-of-life (Ruggieri et al., 2009), was followed. Therefore, the state of the art points out that the viticulture stages were frequently studied, whereas a limited attention was paid on the industrial vinification stages. Indeed, very rarely, in the literature, the emissions related to the single industrial stages were determined. In this work, the industrial vinification stages; i.e., preliminary phases, wine clarification, fermentation, cleaning, refining, bottling, distribution and end-of-life of the production of a high quality Italian white wine were deepened using a LCA approach. The critical stages were identified and alternative solutions to reduce the carbon dioxide emissions were proposed.

2. LCA methodology

LCA is a multi-stage analysis in which a broad set of data related to the life-cycle of a product of a process are properly collected and organized in order to compare different products, different life-cycle of the same product or to individuate the most critical phase of a life-cycle from the environmental perspective. In the following sub-sections, the four main steps that constitute the LCA methodology are presented: 1) goal definition and scope; 2) functional unit; 3) system boundaries; 4) life cycle inventory.

2.1 Goal definition and scope

Goal definition is one of the most important phases of the LCA methodology, because the choices made at this stage influence the entire study. The purpose of this study is to evaluate the environmental impacts of a high quality white wine produced in Southern Italy and exported in the whole country and in China. Figure 1 represents a scheme of the industrial wine production chain.

2.2 Functional unit

The definition of the functional unit (FU) is based on the quantity or mass of the product under analysis, and it is a reference to which all the inputs and outputs have to be related. The chosen functional unit is one 0.75 L bottle of wine.

2.3 System boundaries

The system boundaries of the analysis were set from grapes transportation to waste disposal. All the activities, the processes and the materials used in the industrial wine production stages were taken into account. The proposal study refers to a “from gate to gate” and "from gate to grave" process, regarding, in particular, the vinification, wine bottling and packaging, distribution and waste disposal. In Table 1, the main activities of the observed process are reported. Activities as the potential impacts regarding the consumption and refrigeration of wine in the consumer’s home were not taken into account, because their contribution is very minor in total life cycle impacts (Point et al., 2012). Another activity that has not been included is the transportation of wastes as it was considered negligible (Neto el al., 2013). Others activities concerning the cork stoppers and the caps production as well as the labelling materials used in the bottles were also not considered in the study.

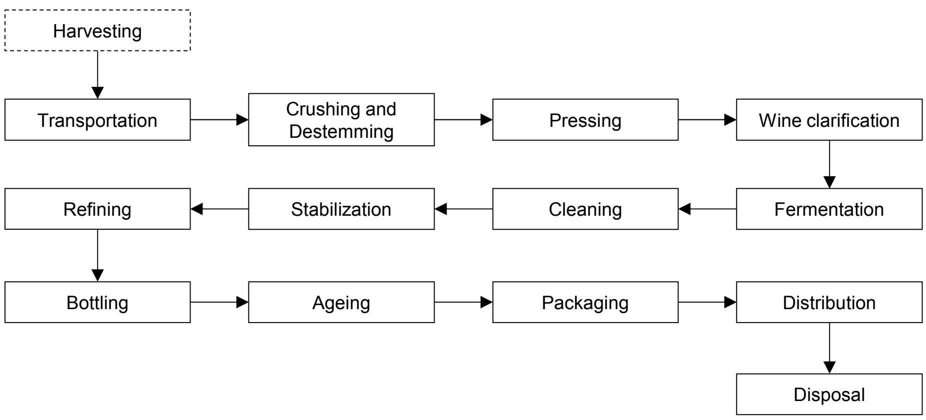

Figure 1: Scheme of the industrial wine production chain

Table 1: Process details and assumptions

Process	Characteristics and details
Grapes supply to facility	Transport by truck, 28 t from Giffoni Valle Piana, Battipaglia, Giovi
Energy supply to facility	Italian energy mix low voltage
Crushing and destemming	Energy supply
Pressing	P = 1.3 bar; Energy supply
Wine clarification	T = 10 °C; t = 24 h; Energy supply for cooling process, enzymes addition
Fermentation	T = 16 °C; t = 20 d; Yeast addition, heat removal
Cleaning	Energy supply
Stabilization	Potassium metabisulfite (MBK) addition
Refining	T = 16 °C; t = 4 m in steel; heat addition/removal
Bottling	White glass (0.75 L); Energy supply, supporting materials and components supply
Packaging	6 bottles; Energy supply, supporting materials and components supply
Disposal	Energy supply, natural resources use for recycling and landfill

2.4 Life cycle inventory (LCI)

The life cycle inventory (LCI) is one of the most effort-consuming step and consists on the activities related to the search, the collection, and interpretation of the data necessary for the environmental assessment of the observed system. The Ecoinvent database was employed as the principal source of background data and the LCA study is conducted using the LCA software SimaPro 8.0.3 in accordance with the reference standard for LCA (i.e., ISO 14040-14044). However, the majority of the processes and materials information required for the analysis are specific of the observed system and the collection of these data was performed using questionnaires, phone and personal interviews for each industrial phase of the wine chain production. For the waste disposal, we assumed that all the organic wastes were composted, labels and cork stoppers were deposited in landfill, whereas for the glass bottles, landfill and recycling were considered. For each unit process within the system boundary, input data, such as energy, water, natural sources and output data in terms of emission to air, water and soil were collected. Table 2 lists the main energy and direct material input to the product systems under the study of a 0.75 L bottle of wine.

3. Results and discussion

The aim of this study is the interpretation of the data collected during the LCI phase and the evaluation of the impact on the environment associated to each industrial stage of the white wine production. In particular, among the different impact categories, the global warming or greenhouse effect is related to the rise in the Earth's climate system average temperature; it is strictly related to the presence of greenhouse gases, mainly carbon dioxide, methane, nitrous oxides and chlorofluorocarbons, due to human activities, that generates an increase in the temperature in the atmosphere to a level above normal. The Global Warming Potential (GWP) is a measure of how much heat a greenhouse gas traps in the atmosphere and compares this amount of heat to the amount of heat trapped by a similar mass of carbon dioxide. The GWP of the main stages of the wine production is reported in Figure 2 (on the left, also the raw materials were taken into account, whereas, on the right, they were not considered).

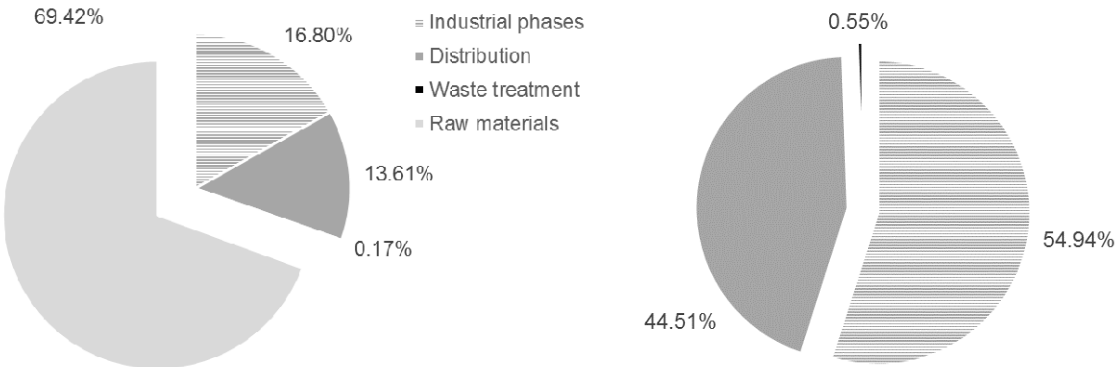

Figure 2: Relative contributions (%) to global warming potential for the main phases of the wine production

Table 2: Life cycle inventory of the main inputs for the three options investigated (tkm is tonne-kilometre).

Industrial Phase	Input	Unit	-2s	mean	+2s
Transportation	Transport by truck	tkm		1.61E-02	
Crushing and destemming	Electricity	MJ		3.58E-03	
	Grapes	kg		1.36E+00	
	Output				
	Stalks	kg		4.77E-02	
Pressing	Destemmed grapes	kg		1.31E+00	
	Electricity	MJ		5.04E-03	
	Output				
	Pips and skins	kg		5.26E-01	
Wine clarification	Must	kg		7.88E-01	
	Enzymes	kg		1.81E-05	
	Electricity	MJ		3.53E-04	
	Electricity for cooling	MJ	3.12E-01	4.04E-01	4.96E-01
	Output				
	Lees	kg		3.94E-02	
Fermentation	Must	kg		7.49E-01	
	Yeast	kg		2.70E-04	
	Electricity for cooling	MJ	1.33E-03	4.71E-03	8.09E-03
	Output				
	Carbon dioxide	kg		5.39E-02	
	Ethanol	kg		1.47E-04	
Cleaning	Wine	kg		7.49E-01	
	Electricity	MJ		2.04E-03	
	Output				
	Lees	kg		7.49E-03	
Stabilization	Wine	kg		7.41E-01	
	MBK	kg		9.64E-05	
Refining	Wine	kg		7.41E-01	
	Electricity for heating	MJ	6.71E-02	4.14E-02	1.57E-02
Bottling	Electricity	MJ		9.00E-03	
	Wine	kg		7.41E-01	
	Glass bottle	kg		4.00E-01	
	Cork	kg		1.30E-02	
	Capsule	kg		2.00E-03	
	Label	kg		3.00E-03	
	Output				
	Bottle of 0.75 L	m^3		7.50E-04	
	Wine loss	kg		3.71E-03	
Packaging	Number of bottles	p		6	
	Cardboard package	m^2		1.39E-02	
	Electricity	MJ		7.41E-04	
Distribution	Transport by lorry	tkm		3.68E-01	
	Transport by barge tanker	tkm		4.86E-02	
	Transport by transoceanic tanker	tkm		3.33E+00	
Waste management	Glass bottle	kg		4.00E-01	
	Capsule	kg		2.00E-03	
	Label	kg		3.00E-03	
	Cork	kg		1.30E-02	

Therefore, the contribution of the industrial stages, excluding the raw materials, is equal to 54.94 %. In the following, the quantitative results will be presented not taking into account the impacts related to the production of the raw materials, considering that the reduction of the impacts related to their production is out of the scopes of the work. Among the industrial stages, clarification, fermentation and refining take place at fixed temperature and are the ones that mainly affect the carbon dioxide emissions. Indeed, GWP is strictly linked to the electricity for cooling and heating, therefore heating sensitivity analysis to individuate the main variables affecting the electricity consumption was made. The analysis revealed that the room temperature considerably affects the emissions of fermentation stage (Pearson coefficient, PC, equal to 0.475), clarification stage (PC = 0.262) and refining (PC = -0.259). Therefore, a study on the effect of room temperature on the carbon dioxide emissions during the wine production (never performed in previous papers) was made, considering the mean room temperature for the years 2010-2013 in the months during which the industrial stages under study occur. In particular, during wine clarification (24 h) and fermentation (20 d), the mean room temperature was 18.8 °C. During refining (for the subsequent 4 months), the mean temperature lowered to 13.2 °C. The standard deviations (σ) of those values were evaluated and the GWP of each stage during the wine production was calculated at temperatures equal to the mean value ± 2σ (therefore, for wine clarification and fermentation at 16.8 and 20.8 °C, and, for refining, at 11.5 and 15 °C). The GWP measured in $kgCO_2$ equivalent/FU, for the three options, is reported in Figure 3a. As can be noticed, the room temperature has an effect on the global warming potential; in particular, to reduce the carbon dioxide emissions, the clarification and fermentation should occur in a place with a lower room temperature, whereas the refining has to occur at higher temperatures. A different choice could be to produce the wine in a place with a storage in a cellar (or cavern) with a naturally stable temperature (constant during the different stages) properly chosen to minimize the GWP. First of all, the CO_2 emissions were evaluated, considering that the industrial stages are conducted at constant temperature, without taking into account the emissions related to the transfer in a different location. The GWP of the industrial stages (from preliminary phases to bottling) are reported in Table 3 and in Figure 3b.

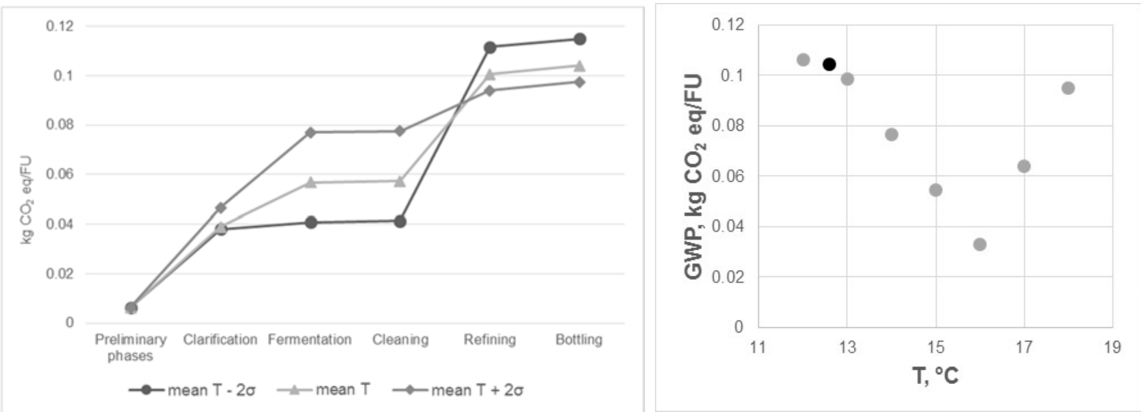

Figure 3: Global warming potential of the industrial stages during the wine production (kg CO_2 eq/FU); (a) cumulative emissions obtained at different room temperatures; (b) global emissions at constant cellar temperatures.

Table 3: GWP (in $kgCO_2$ equivalent/FU) at different constant temperatures.

GWP	Present situation	T=18 °C	T=17 °C	T=16 °C	T=15 °C	T=14 °C	T=13 °C	T=12.3 °C
	1.04E-01	9.47E-02	6.37E-02	3.27E-02	5.45E-02	7.65E-02	9.84E-02	1.04E-01

As shown in Figure 3b, the emissions of the actual situation (GWP = 1.04E-01 $kgCO_2$ equivalent/FU) are matched at 12.3 °C (dark circle); the minimum value of the GWP is reached at 16 °C that is the temperature at which fermentation and refining have to take place. Obviously, conducting the vinification in a cellar with that room temperature will avoid the cooling or heating of the surroundings. Therefore, if there is not a cellar (at constant temperature) in the proximity of the wine firm, it is necessary to transfer the must in a place where that cellar is available. The hypothesis of transferring the must induces the need of looking for a trade-off between the higher emissions related to the transfer and the lowering of the carbon dioxide emissions due to the reduced conditioning ΔT. For each cellar temperature, the maximum distance that can be travelled (using Lorries Euro 5 with a capacity of 32 t), in order to have GWP equivalent to the actual solution, were evaluated and reported in Table 4 and in Figure 4.

Table 4: Maximum distances for the placement of the cellar at constant temperature.

	T=18 °C	T=17 °C	T=16 °C	T=15 °C	T=14 °C	T=13 °C	T=12.3 °C
km	28	123	217	151	84	17	0

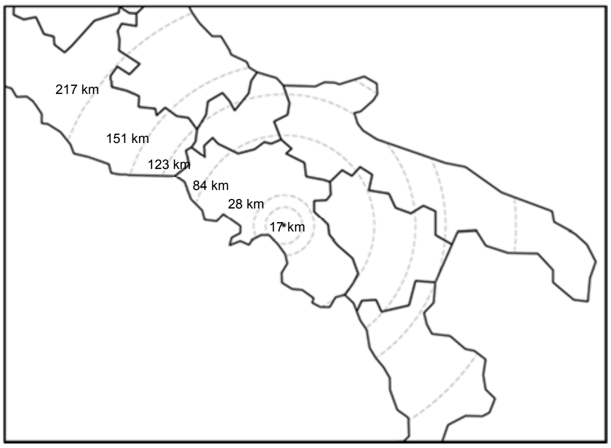

Figure 4: Maximum distances (in straight lines) for the placement of the cellar.

4. Conclusions

A quantitative analysis of the GWP of an Italian white wine production was made. The stages at controlled temperatures are the ones that mainly affect the GWP, therefore, considering that the process temperatures cannot be varied to not alter the produced wine, a study on the effect of the room temperature was performed. After a sensitivity analysis, to reduce carbon dioxide emissions, the effect of the room temperature on the GWP of clarification, fermentation and refining stages was verified. An improvement of the industrial stages was, then, proposed with different scenarios based on the transfer of some phases in cellars (at constant temperatures) far away the firm; for each scenario, the maximum distance compliant with the cellar position was determined.

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