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Life Cycle Assessment of Red and White Wines Production in Southern Italy

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In the last years, the wine production industry has gradually focused its attention in the improvement of the product quality rather than in the production of great quantities. This tendency has allowed the entrance in the market of various small wine producers that have developed new product trademarks of good qualities on a small scale. Recently, the environmental sustainability is establishing to determine the product quality.
In this study, a Life Cycle Assessment (LCA) was carried out to compare the environmental impacts and the energy efficiency of four kinds of wines made by a small producer in the southern part of Italy. The system boundary covered the industrial life-cycle stages of wine production. In particular, in this paper, four stages were considered: vinification, bottling, packaging and waste disposal treatments. The aim of the work is to compare the environmental impact of a high and medium quality wine (either in the case of white wines or in the case of red wines) to understand how to address the production toward a higher sustainability. The analysed products have been realized using different processes and different raw materials, depending on the specific characteristics and kind (red or white) of produced wine. The materials and energy consumption and the emissions to air, soil and water were reported to the chosen functional unit (1 bottle of Italian wine). The data were analysed using SimaPro 8.0.2 software and the Ecoinvent database, in accordance with the reference standard for LCA (i.e., ISO 14040-14044) to identify environmental key performance indicators (KPIs).

1. Introduction

This work concerns the environmental impact and the energy efficiency of different wines produced in the southern part of Italy and exported in the whole country. A recent trend in the wine production industry led to the production of products of higher qualities rather than quantities; this tendency opened the market doors to small wine producers, that have developed good qualities wines on a small scale. Four main stages have to be considered in the production of wine: viticulture (related to grapes cultivation), wine production and bottling (from vinification to storage), wine distribution and sales, and disposal of empty bottles. Life cycle assessment (LCA) has been already used to evaluate the environmental impact of wine. LCA is an internationally recognized and ISO standardized accounting tool to quantify the environmental impacts of a product, a process or a service throughout its life cycle, by identifying, quantifying and evaluating all the resources consumed and all the emissions and wastes released in an analysis known as a "from cradle to grave".The LCA analysis has been largely used in many industrial sectors, such as, for example, bioplastics (Petchprayul et al., 2012) or biodiesel (Wibul et al., 2012) or automotive (La Rosa et al., 2013) industries. In the last years, various LCA analyses have been performed in the case of agricultural productions, that are more complex because, for the agricultural phase, the LCA methodology is not well established, since the process cannot be easily standardised (Haas et al., 2000). Among the agri-food products, wine has been one of the most studied and several LCA papers using a *cradle to grave* analysis have been published. In particular, Gazulla et al. (2010) identified the most critical, from the point of view of the environmental impacts, life cycle stages of a Spanish red wine production and compared its environmental performance with other wines and beers. Bosco et al. (2011) made a carbon footprint (life cycle of greenhouse gases emitted in the atmosphere) analysis of four high quality wines produced in the

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Maremma Italian district, including all the products' life cycle stages, with a special interest on the agricultural phase. Other studies, like the one made by Ardente et al. (2006) or by Neto et al. (2013), used a *cradle to gate* approach, considering the distribution but not the waste disposal stage. The remainder studies considered the waste disposal but not the distribution (Pizzigallo et al., 2008). The analysis of the state of the art underlines that a limited attention has been paid to the industrial wine vinification stages. Therefore, the step forward of this paper with respect to the existing literature is the in-depth analysis of the single industrial vinification stages; i.e., preliminary phases, wine clarification, fermentation, cleaning, refining and bottling to verify the relevance of each phase on the total environmental impact. The results of the LCA analysis are related to the industrial stages of four different wines made by a small Italian producer.

2. LCA methodology

LCA is a multi-stage analysis in which a broad set of data, regarding the life-cycle of a product or a process, if properly collected and organized, are used 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 the life cycle of four different wines from Southern Italy, one Red of High Quality (RHQ), one Red of Medium Quality (RMQ), one White of High Quality (WHQ) and one White of Medium Quality (WMQ). Figure 1 represents a scheme of the industrial wine production chain. The analysis is focused on the wine production stages to highlight the different four wines environmental performances.

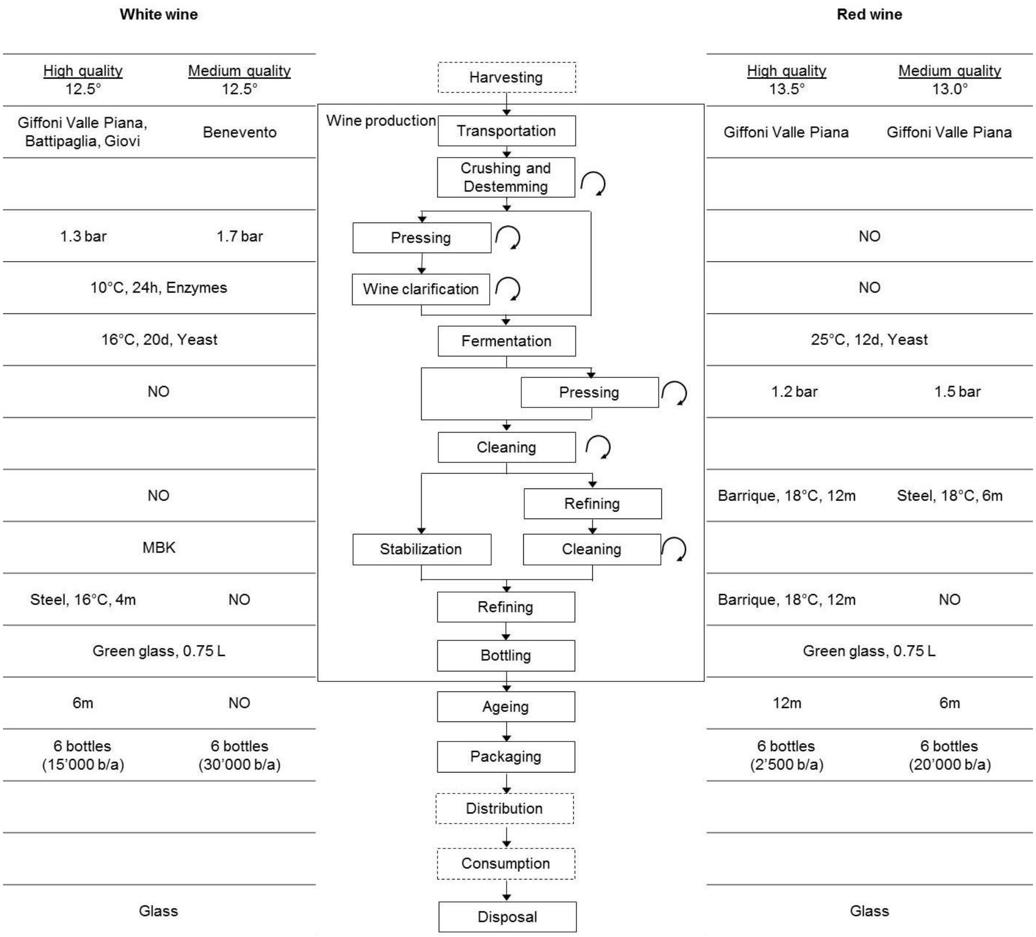

Figure 1: Scheme of the industrial wine production chain

2.2 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 8.0.2 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 each type of wine, the procedure for the determination of energy consumption, emissions, and yields followed the stages represented in Figure 1 and took into account mass and energy balances typical of each transformation and of the equipment owned by the producer. For each unit process within the system boundary, input data; i.e., energy, water, natural sources, temperatures and pressures, 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 purpose of this study consists on the interpretation of the data collected through the LCI phase, and the evaluation of the impact that different wine' productions have on the environment. The inventory results are classified by different categories of impact in accordance with impact assessment step. In Figure 2, the relative contribution of the four kind of wines production on each impact category are reported. The proposed histogram reports the resulting performances in terms of global warming potential, ozone layer depletion, photochemical oxidation, acidification, eutrophication and non-renewable energy consumption.
The global warming is related to the continuing rise in the average temperature of Earth's climate system and is due to the presence in the atmosphere of greenhouse gases, mainly carbon dioxide, methane, nitrous oxides and hydrofluorocarbons, produced by human activities. The global warming potential (GWP) is a measure of how much heat a greenhouse gas traps in the atmosphere; it measures the equivalent damage caused by an equal mass of carbon dioxide (CO_2) over a specific time interval. In our studies, we considered the GWP 100, referred to a period of 100 years. The ozone layer depletion is related to the decline in the total volume of ozone in Earth's stratosphere and to the springtime decrease in stratospheric ozone over polar regions, commonly named ozone hole. The photochemical oxidation is the resulting combination of solar radiation with unburned hydrocarbons and nitrogen oxides present in the exhaust fumes. The acidification is related to decrease in the pH of oceans, rivers, lakes and forests, caused by the uptake of carbon dioxide, sulfur oxides and nitrogen oxides in air. The eutrophication is related to the addition of artificial or natural substances, such as nitrates and phosphates, through fertilizers or sewage, to an aquatic system, causing negative environmental effects like the depletion of oxygen in the water. Finally, the non-renewable energy consumption is related to the use of resources that do not renew themselves at a sufficient rate for sustainable economic extraction like fossil fuels (coal, petroleum and natural gas). The white and red medium quality wines (WMQ and RMQ) have a lower impact than the high quality wines (WHQ and RHQ) for each of the considered impact categories.

Table 1: Process details and assumptions.

Process	Characteristics and details
Grapes supply to facility	Transport by truck, 28 t Lorry and 40 tons Lorry, EU average consumption
Energy supply to facility	European energy mix
Crushing and Destemming	Energy supply
Pressing	Energy supply
Wine clarification	Energy supply for cooling process, enzymes addition
Fermentation	Yeast addition, heat removal
Cleaning	Energy supply
Stabilization	Potassium metabisulfite addition
Bottling	Energy supply, supporting materials and components supply
Packaging	Energy supply, supporting materials and components supply
Product end-of-life	Energy supply, natural resources use for recycling, landfill and incineration

Table 2: Life cycle inventory of the main inputs for the four wines investigated.

Industrial Phase	Input	Unit	WHQ	WMQ	RHQ	RMQ
Transportation	Transport by truck	km.t	1.42E-02	9.92E-02	2.92E-03	2.40E-03
Crushing and destemming	Electricity	MJ	3.16E-03	2.84E-03	3.84E-03	3.16E-03
	Grapes	kg	1.20E+00	1.08E+00	1.46E+00	1.20E+00
	Output					
	Stalks	kg	4.20E-02	4.64E-02	6.56E-02	5.53E-02
Pressing	Destemmed grapes	kg	1.16E+00	1.03E+00		
	Electricity	MJ	1.33E-02	1.19E-02		
	Output					
	Pips and skins	kg	3.71E-01	2.48E-01		
Wine clarification	Must	kg	7.88E-01	7.84E-01		
	Enzymes	kg	1.81E-05	2.74E-05		
	Electricity	MJ	3.53E-04	3.51E-04		
	Electricity for cooling	MJ	1.02E-01	9.92E-02		
	Output					
	Lees	kg	3.94E-02	3.14E-02		
Fermentation	Must	kg	7.49E-01	7.53E-01	1.39E+00	1.15E+00
	Yeast	kg	2.70E-04	3.01E-04	1.88E-04	1.72E-04
	Electricity for cooling	MJ	4.21E-02	3.27E-02	1.93E-01	2.66E-02
	Output					
	Carbon dioxide	kg	5.39E-02	5.41E-02	1.16E-01	9.11E-02
	Heat	MJ	6.01E-05	6.03E-05	1.29E-04	1.02E-04
Pressing	Wine	kg			1.39E+00	1.15E+00
	Electricity	MJ			1.60E-02	1.32E-02
	Output					
	Peels	kg			6.13E-01	3.67E-01
Cleaning	Wine	kg	7.49E-01	7.53E-01	7.80E-01	7.80E-01
	Electricity	MJ	2.04E-03	2.05E-03	2.13E-03	2.13E-03
	Output					
	Lees	kg	7.49E-03	1.13E-02	3.90E-02	3.90E-02
Stabilization	Wine	kg	7.41E-01	7.41E-01		
	MBK	kg	9.74E-05	1.20E-04		
Refining	Wine	kg	7.41E-01			
	Electricity	MJ	3.19E-02			
	Electricity for cooling	MJ	3.82E-02			
Final cleaning	Wine	kg			7.41E-01	7.41E-01
	Electricity	MJ			9.94E-04	9.94E-04
	Output					
	Lees	kg			3.70E-03	3.70E-03
Bottling	Electricity	MJ	9.00E-03	9.00E-03	9.00E-03	9.00E-03
	Wine	kg	7.41E-01	7.41E-01	7.41E-01	7.41E-01
	Glass bottle	kg	6.50E-01	6.50E-01	6.50E-01	6.50E-01
	Cork	kg	1.30E-02	1.30E-02	1.30E-02	1.30E-02
	Capsule	kg	2.00E-03	2.00E-03	2.00E-03	2.00E-03
	Label	kg	3.00E-03	3.00E-03	3.00E-03	3.00E-03
	Output					
	Bottle of 0.75 L	m^3	7.50E-04	7.50E-04	7.50E-04	7.50E-04
	Wine loss	kg	3.77E-03	3.77E-03	3.77E-03	3.77E-03
Packaging	Number of bottles	p	6	6	6	6
	Cardboard package	m^2	1.39E-02	1.39E-02	1.39E-02	1.39E-02
Waste management	Glass bottle	kg	6.50E-01	6.50E-01	6.50E-01	6.50E-01
	Capsule	kg	2.00E-03	2.00E-03	2.00E-03	2.00E-03
	Label	kg	3.00E-03	3.00E-03	3.00E-03	3.00E-03
	Cork	kg	1.30E-02	1.30E-02	1.30E-02	1.30E-02

Among the two high quality wines, the white one has an higher impact on global warming potential, whereas the red one has an higher impact on the other impact categories: ozone layer depletion, photochemical oxidation, acidification, eutrophication and non-renewable energy consumption. In order to underline the differences on the environmental impact of the vinification stages of the four Italian wines, the Global Warming Potential (GWP) and the corresponding carbon dioxide equivalent emissions of the industrial phases are reported in Figure 3. The GWP of the phases within the system boundary of the four investigated wines was found to lie between 0.18 and 1.28 kg CO_2-eq./bottle, showing a comparable value with literature (Bosco et al., 2011). The high quality wines (WHQ and RHQ) showed the higher GWP/bottle, followed by the other white wine (WMQ) and then by the other red (RMQ). The preliminary phases (transportation, crushing and destemming, and pressing) were put together, but their contribute to GWP was very low (it goes from 0.0024 % for the RMQ wine to 0.076 % for the WMQ wine). The clarification is performed just in the case of white wines, and it represents the 1.3 % in the case of the high quality wine and the 6.8 % in the case of the medium quality wine. The refining stage, where the wines are taken in barriques (RHQ) or in steel containers (WHQ, RMQ) is relevant only in the case of the WHQ wine (79.2 % of the total GWP). Indeed, for the red wines (RHQ and RMQ), the refining stages are taken at 18 °C, that was the mean temperature of the cellars where the wines were stored; whereas, in the case of the WHQ wine, the refining stage is taken at 16 °C, therefore the consumption for refrigeration systems that increased the electricity consumption has to be taken into account.

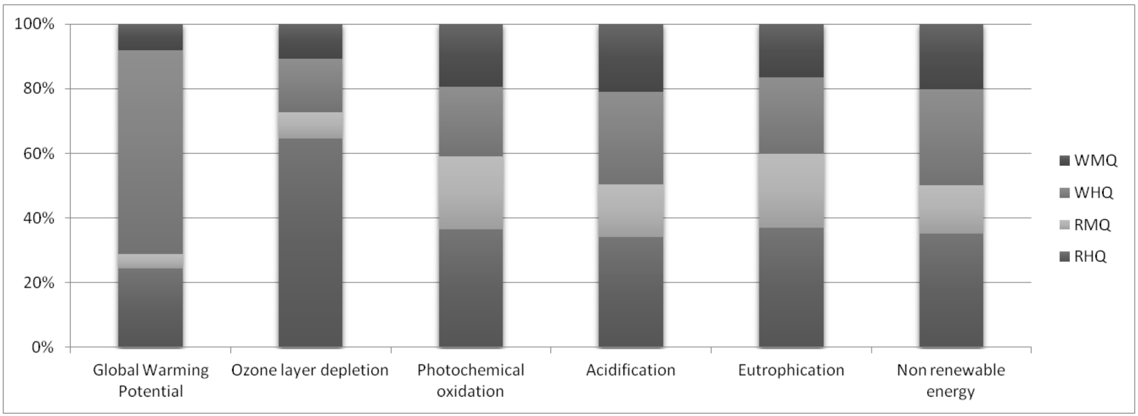

Figure 2: Impact assessment for different wine productions

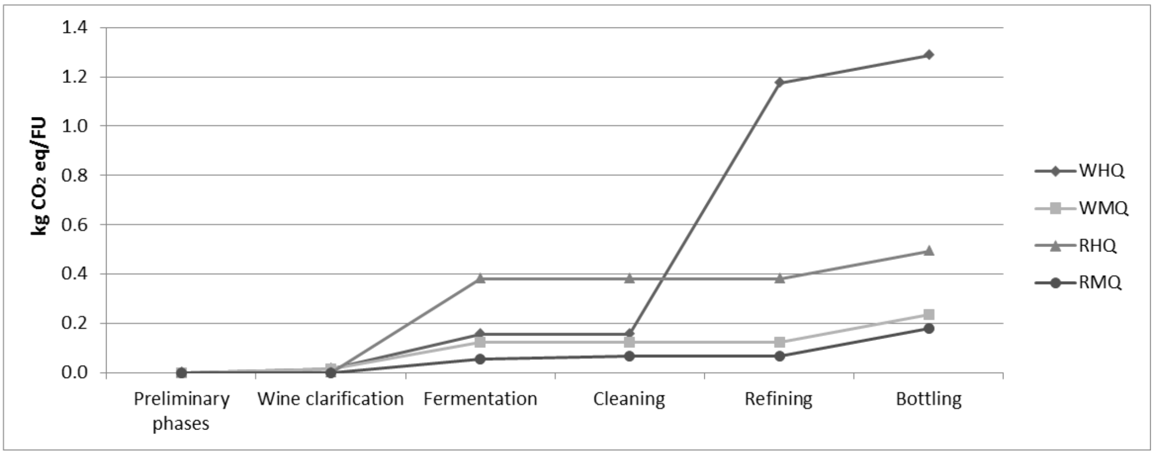

Figure 3: GWP of main processes occurring in the production stages (kg_{CO2eq}/FU)

As a consequence, the fermentation and bottling phases are particularly important for the red wines and for the white medium quality wine: in particular, the fermentation stage (taken at 16 °C for the white wines and at 24 °C for the red wines) has a GWP impact of 10.8 %, 45.6 %, 77.2 % and 30.9 % of total GWP for WHQ, WMQ, RHQ and RMQ wines, respectively.

4. Conclusions

The purpose of this study is to present a quantitative analysis of the environmental performances for different Italian wines production. The high quality white wine has the higher impact on the global warming potential, due to its refining stage, during 6 months at controlled temperature. Among the other industrial stages, the most relevant are, for all the kinds of wines, the fermentation at controlled temperature stage and the bottling one. Further developments will include a sensitivity analysis and will be also focused on the widening of system boundaries, in order to study in details the contribution of other significant processes and activities to the wine LCA.

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