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Sustainability evaluation of a Portuguese “terroir” wine

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Abstract. The challenges of sustainability are transversal to all human activities, and the wine sector has its own role to play in the march for a more sustainable development. The proper definition of the most adequate measures and/or policies must be based on an objective and quantitative evaluation of the sustainability of a product or process. In this work the sustainability of a “terroir” wine is assessed taking into account its life cycle and using the following indicators: carbon and water footprint, material intensity, solid waste generated, worker turnover rate, investment in H&S training and EBITDA. All indicators are expressed per functional unit of 0.75 L of wine. The evaluation used data from the company complemented with data/information from the literature or life cycle inventory databases. To account for climatic variability, data from three consecutive years was used. Average values of 3.51 $kgCO_2eq$ and 481.4 L per functional unit were obtained for the carbon and water footprint respectively, both values within the range of values reported in the literature.

1. Introduction

The last decades witnessed an increased awareness of the negative impacts and everlasting damages that human activities have in the environment. Examples include the growing emissions of gases that contribute to climate change, mainly due to the consumption of fossil fuels for energy generation, land use change for crop cultivation, among many others. The realization that the continuation of the current practices, especially of production and consumption, seriously impacts the environment and has positioned sustainability as the cornerstone of current development strategies and policies, either general or focused in specific areas and/or sectors of activity. Currently, the most comprehensive strategy is the UN Sustainable Development Goals (SDG) [1] that defined 17 specific areas that encompass all the relevant environmental, economic, and societal systems, central to promote a march towards a more sustainable development. The SDG goals consider the fact that, although the issues are global, the solutions to be implemented need to be local, taking into account the sectorial and/or regional aspects to ensure that their goals are reached.

The wine sector also has its own role in the march towards sustainability. Wine production is one of the oldest industries in the agri-food sector and has significant economic and even social-cultural importance in many world regions, currently encompassing all continents except Antarctica. Depending on the local practices and conditions, wine making may include land use changes, irrigation, utilization of chemicals in various steps of its life cycle, packaging and transportation, among others; activities that have different sustainability impacts. In a SDG perspective, wine production can be placed directly in goal 12 (responsible production and consumption). Still, indirectly it is also relevant to goal 2 (zero hunger) as it is an agricultural activity, to goal 6 (clean water and sanitation) as it may involve irrigation and utilization of chemicals, goal 13 (climate change) as energy is consumed in the production processes, and goal 15 (life on land) as vine cultivation requires arable land.

The issues of sustainability represent a challenge and are starting to be recognized by the wine production and distribution companies as relevant to their future operations and/or competitiveness [2,3]. Beyond the need to comply with the ever-increasing stringent regulations and/or legislations, as for example reductions in the greenhouse gas emissions, or the stakeholders demands, there are also business opportunities, as costumers are starting to pay more attention to the environmental and/or sustainability issues, although to some extent it is still a matter of discussion [4–8].

The issues of sustainability in the wine sector are acknowledged by the many existing regional and international organizations that are trying to encourage and support winegrowers and producers by providing them with definitions and tools to facilitate the adoption of more sustainable practices, since most of them are small companies and lack the financial and human resources needed. Therefore, they have developed and implemented various programs, certification schemes and other activities, most of them at a regional or national scale [9–12]. At a global scale, the International Organization of Vine and Wine (OIV), the largest multilateral international organization operating in the wine sector, decided to harmonize the various approaches to avoid unfair competition and promote the communication and the transfer of information between the various stakeholders. Thus, in 2004, OIV adopted a resolution [13] stating the definition and general principles of sustainable viticulture, later actualized by a new resolution in 2016 [14]. Based on those resolutions, guidelines were developed concerning specific issues pertinent to sustainable development, in particular for the production, processing and packaging of products [15], principles of organic viticulture [16], and greenhouse gas emissions accounting [17,18].

Although the aforementioned guidelines and tools can support the definition and implementation of sustainability improvement measures, they should be based, as much as possible, on quantitative and objective evaluations of the current situation. In the literature, it is already possible to find a good number of studies in which the evaluation of the sustainability of wine production is studied and results are reported. Most studies focused on specific wineries/vineyards, and are based on a Life Cycle Thinking (LCT) approach using the Life Cycle Assessment (LCA) methodology as defined in the ISO 14040 standard [19]. Many examples of LCA studies can be found in the literature [20–23], as well as reviews of the application of LCA to wine production systems [24,25]. The various wine life cycle stages are considered to various degrees, depending on the study objectives and/or availability of data.

The bulk of the available studies focused on the environmental aspects, as data is easier to obtain, and quantification methodologies are more developed, although some studies have also considered economic and even social aspects of sustainability [26,27]. Other studies considered only specific indicators, especially the carbon footprint (CF) and the water footprints (WF) [28–30]. Extensive reviews on the application of the carbon footprint concept to wine production can be found in the literature [32–35]. Both indicators are directly linked to various key aspects of wine production such as energy consumption, land management and transportation related to the CF, and water usage for the WF. As both indicators are directly related to important aspects of sustainability, they are consensual, especially the CF, and easily understood by the various stakeholders. Also, they are seen as adequate indicators for communication and marketing purposes, although work still needs to be done on their evaluation methodologies.

Albeit the extensive work already done in this area, there is still room for improvement, as for example in the sustainability evaluation of wine produced in large companies, where various brands of wine are produced at the same vineyard and/or facility. This work tries to fulfill that gap by performing a sustainability evaluation of a “terroir” wine produced in a large company with a large portfolio of brands, in which certain facilities are shared to produce them.

2. Sustainability evaluation

The sustainability evaluation of a product or process should be based, as much as possible, on a quantitative framework and on a LCT approach. This way it will be possible to identify which aspects most contribute to the unsustainability of the system under study, and support decision making or the definition of policies to improve the system sustainability. In this work the framework proposed by Martins et al. [36] will be followed, as it was already used to assess different products and processes, such as for example biofuels and wine [9,36–40]. It consists of an interlinked sequence of steps that should be followed sequentially to ensure a proper sustainability evaluation, as shown in Fig. 1. The framework draws heavily from the LCA methodology [19], nowadays considered the most adequate form of evaluating the environmental impacts of a product or process [41,42].

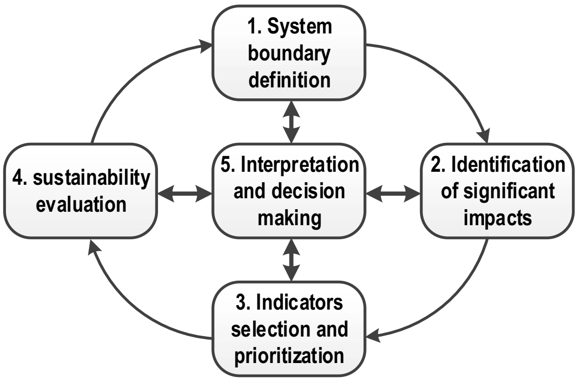

Figure 1. Sustainability evaluation framework [36].

The first step of the sustainability evaluation framework consists of the system boundary definition, which includes all the life cycle stages relevant for the study, based on its objective. Thus, it includes processes and flows of materials and energy, and the economic, social and cultural aspects that may be relevant for the study objective. Depending on the study goals, more or less detail may be given to some parts. Also, in this stage it is defined the functional unit (FU) that, similarly to what is done in the LCA methodology [19], represents a measure of the function of the system performance, and allows a more accurate comparison with other products or processes’ results. In the second step, the potential relevant environmental, social and economic impacts are identified. Besides a detailed analysis of the system, involving not only the production processes but also taking into account the interests of the various stakeholders, information from the literature and consensual practices is also taken into account. These impacts are expressed in the form of indicators, independent from each other, and representing a specific impact. The set of indicators should be as small as possible, but not so small that valuable information is lost. Here, the consensual indicators, already applied in practice, should be used as much as possible. In the third step, indicators are prioritized and calculated, using data and information from the processes under study, and should be used preferentially combined with other information or even with life cycle inventory data. In the fourth step, the system sustainability evaluation is done based on the calculated values, aiming the identification of the hotspots and support decision making. Common to all steps there is an interpretation/decision making step, as all the information and data acquired during the other stages should be critically assessed to identify which one is relevant to the sustainability evaluation goals. Moreover, the framework forms a closed loop to account for changes in the system, data available, technological improvements, changes in the political and/or environmental priorities/concerns that need to be considered, whenever necessary, to improve the sustainability evaluation [9,37–42].

2.1. Study goals and scope

This work aims to perform a sustainability evaluation, of a Portuguese "terroir" wine produced in the upper Douro valley, a region with a hot summer Mediterranean climate, classified as CSa in the Koppen climate classification [43] with strong annual variations in the precipitation values. The wine is produced with grapes from a single vineyard using standard viticulture practices in small volumes, around 30,000 bottles per year, although the quantity produced varies each year depending on the particular climatic conditions.

2.2. System boundary definition

The life cycle of the "terroir" wine starts with the growth and harvesting of the grapes. For the wine under study standard cultivation techniques are used, taking into account the specificities of the soil and climate at the vineyard site. When the grapes are considered ripe, they are harvested and sent to the wine production facility. There, they are registered, by weight and grape variety, and some parameters are analyzed, relevant to control the fermentation process. In particular the density, pH, total acidity and the sugar contend that allows to estimate the alcoholic degree of the resulting wine.

Then, the grapes are discharged in hoppers that transport them to the crushers, where the must is produced, and the grapes stalks are separated. The later are composted to be used as fertilizer in the vineyard. The fermentation is done in stainless steel fermentation tanks in which oenological products, in particular tartaric acid and yeasts are added to the wort to control the process and ensure the final wine quality. The fermentation lasts for about six days. Upon completion, the wine (liquid) is separated from the marc (solid) by pressing, and the latter is sent to other companies to produce brandy or wine spirits by distillation. The wine is then stored in stainless steel tanks to stabilize for a few days. Then, it is transported by truck to other facility, where it is transferred to oak barrels and aged for a period of about one year. After finishing the aging period, the wine is sent to the bottling unit, located in another installation, also used to bottle other brands of wine. The bottled wine is then stored and shipped depending on the distributor and/or costumer orders. The transportation is done to the wine retailers by truck, in Europe, and by ship to other continents. The transportation to the final selling points and by consumers to their homes are not considered, as no data is available for these stages before final consumption.

Figure 2 shows the life cycle stages of "terroir" wines considered for this study, including: viticulture, winemaking, aging, bottling, storage, packaging, preparation for shipping and distribution.

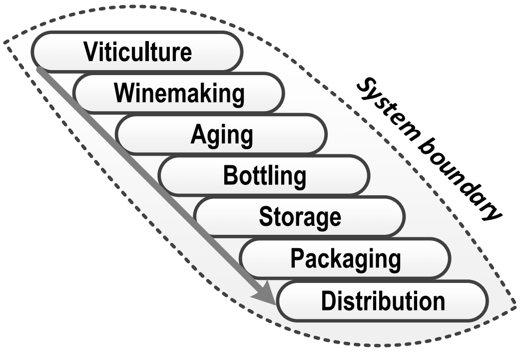

Figure 2. System boundary definition including the "terroir" wines' life cycle stages considered for this study.

2.3. Functional unit

The "Terroir" wine considered in this work is bottled in 0.75 L bottles that is also the capacity of most wine bottles available in the market. Thus, to facilitate the comparison with other wine brands and to minimize production size effects the chosen functional unit (FU) for this study is 0.75 L, corresponding to one bottle of wine.

2.4. Indicators selection and evaluation

As stated above, the sustainability evaluation is based on the definition of indicators that represent, as objectively and accurately as possible, quantitative measures of the environmental, economic, social and cultural aspects deemed relevant, from a sustainability point of view, for the system under study. Thus, from the plethora of different issues, pertinent to sustainability, one must choose those applicable to the wine sector, keeping in mind some general rules independent of the system under study [36]. Some of the most important include the need to choose consensual indicators independent of each other, easy to calculate, not biased, clear and simple to understand by the various stakeholders involved.

Therefore, the following indicators were selected for this study, each one evaluated per FU:

- Carbon footprint (CF);
- Water footprint (WF);
- Material intensity;
- Solid waste generated;
- Worker turnover rate;
- Investment in health and safety (H&S) training;
- Earning Before Interests Depreciation, Taxes and Amortizations (EBIDTA).

The CF is a consensual indicator that represents the impact of a given system's activities and/or processes on climate change. The wine life cycle includes stages that have significant carbon emissions. In particular, viticulture is an agricultural activity, involving soil tillage and soil fertilization, and the agriculture sector is a significant contributor to the global carbon emissions, around 10% in an European context [44]. Moreover, transportation is significant between the various life cycle stages, especially in the final product's distribution. The CF is a good proxy of the energy used in many product or process systems [42]. In this work, the CF was calculated following the guidelines proposed by FIVS [45], developed to be applied directly to the wine and other alcoholic beverages. The guidelines divide the carbon emissions in three scopes or types, corresponding to:

- Scope 1: direct emissions related to fuel consumption in the processes, agricultural practices, carbon sequestration by the vines, waste treatment and disposal;

- Scope 2: indirect emissions from the electricity consumed in the process;
- Scope 3: indirect emissions of embedded carbon in the materials used in viticulture, oenological products, packaging materials, cleaning agents, and transportation.

The division in several scopes facilitates the identification of the most relevant contributors to the overall CF value, and helps define measures or policies to reduce it. Since CF is an indicator related to energy consumption, it can be seen not only as an environmental indicator but also as an economic indicator, as energy costs are significant in the wine production.

The WF is an indicator directly related to water consumption, significant in the wine's life cycle, as it includes agricultural activities, with irrigation whenever necessary, and cleaning operations in the winemaking and bottling life cycle stages. Thus, besides being a measure of the impacts on the water resources, the WF is also relevant from an economic point of view, as lower water consumption leads to lower operating costs.

Differently from the CF, the estimation of the WF of a product or process is still subject of much discussion, and currently there is no consensual methodology to calculate it. In this work, the WF is evaluated using the methodology proposed by Hoekstra et al. [46] in his Water Footprint Manual, which is one of the frameworks most used in practice. Accordingly, the WF of a product is the sum of the direct water consumption in the various life cycle stages, and the indirect water used to obtain the materials and energy used in the wine production. Moreover, the global WF corresponds to three terms: the blue WF (WF_B) corresponding to the consumption of superficial and/or groundwater, the green WF (WF_V) that is equal to the water precipitation, and the grey WF (WF_G) that corresponds to the volume of water necessary to dilute the contaminants generated in the process, harmless according to existing legislation/regulation.

Two more operational related indicators were selected in this work: material intensity and solid waste generated; valuable to assess the process efficiency. They are appropriate from an environmental and also economic point of view, as raw materials consumption and waste generated represent an operational cost. Both indicators were calculated with data supplied by the company.

The definition of social and economic indicators is more complex, as the methodologies available for their evaluation are more complex or not so much developed. Also, there is still no consensus about which aspects should be reported, or even in many cases the data is not available. Taking into account the proposed frameworks [47], two social indicators and one economic indicator were selected. One deals with the worker turnover, a measure of the company labor practices. The other deals with the investment in H&S training, vital to ensure a proper operation of the equipment and processes involved, reducing the work accidents and thus, minimizing the negative economic and social impacts. Finally, the EBITDA is a direct measure of the contribution of the "terroir" wine capacity to contribute to the company revenues and potential profits.

2.5. Inventory analysis

In this work, a significant effort was made to use data directly obtained from the company operations and activities (primary data), as this way there is more representativeness in the sustainability evaluation results. Whenever necessary they were complemented with information or data from the literature, in particular concerning the WF of materials and energy used in the life cycle stages, or carbon emissions from the International Wine Carbon Calculator, IWCC [48], or emission factors for transportation and chemicals used in the wine production, obtained from the EcoInvent V2.1 database available in the LCA software Simapro V7.3.3 [49], and for the electricity consumed from the EDP, a Portuguese electricity supplier [50]. For the water consumed in irrigation, the values supplied by the company were used and for the precipitation data, the information gathered in the meteorological station circa 15–20 km away from the vineyard was used [51].

When making the inventory, two important questions arise that should be considered explicitly: the production variability due to differences on the climate conditions during the viticulture period, and the common utilization of the vineyard and of the winemaking and bottling facilities to obtain other brands of wine. The later issue is relevant when the data is only available in aggregate form, as it is the case in this study, making it necessary to perform some allocation procedures. Two situations were defined: one for the vineyard and wine making stages, and the other for the bottling stage. In both situations it is assumed that the impacts are independent of the wine brand, as they use the same equipment and operational conditions. Therefore, for the vineyard and winemaking facility, a simple proportional allocation was done between the total volume of wine produced and the volume of "terroir" wine under study, and between the total quantity of bottles filled in the bottling unit and the "terroir" wine bottles quantity.

If the production variability between years was not taken into account, different values for the sustainability indicators would be obtained for different years. This situation would hamper decision making, as for example the sustainability hotspots may vary from year to year. Thus, to reduce the production variability, the production data from three consecutive years (2010, 2011 and 2012) was used, deemed sufficient to minimize the effects of climate variability. As the wine undergoes an aging period of two years, followed by one year in the bottle, the data of bottling and expedition, corresponding to the bottles filled and dispatched, are from two years after the wine fermentation. For example, the wine produced in 2010 is bottled in 2012 and dispatched to the distributors in 2013.

3. Results

This section presents the results obtained for each sustainability indicator considered in the "terroir" wine sustainability evaluation, and compares them, whenever possible, with values reported in the literature.

Figure 3 presents the CF values for each of three years considered in the sustainability assessment.

Figure 4 shows the CF obtained for each life cycle stage for the "terroir" wine produced in year 2010.

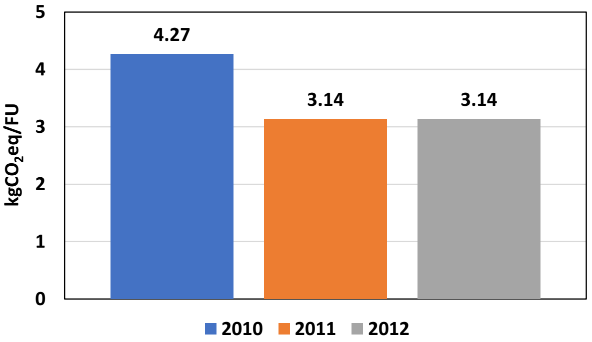

Figure 3. CF of the "terroir" wine's life cycle, for each production year considered in the study.

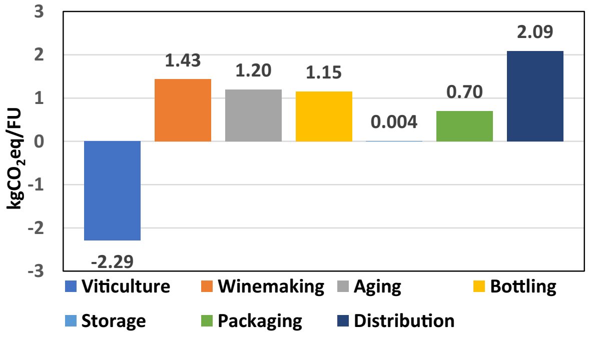

Figure 4. CF associated with each life cycle stage of the "terroir" wine produced in 2010.

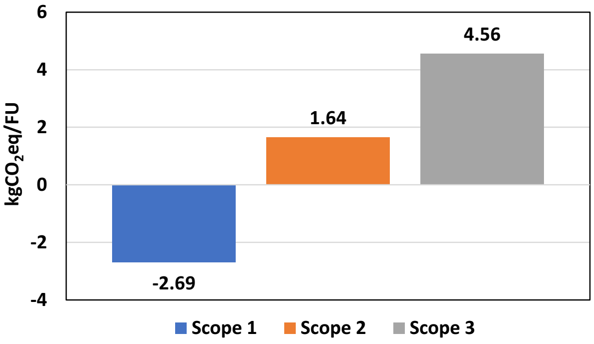

Figure 5. CF average values by scope.

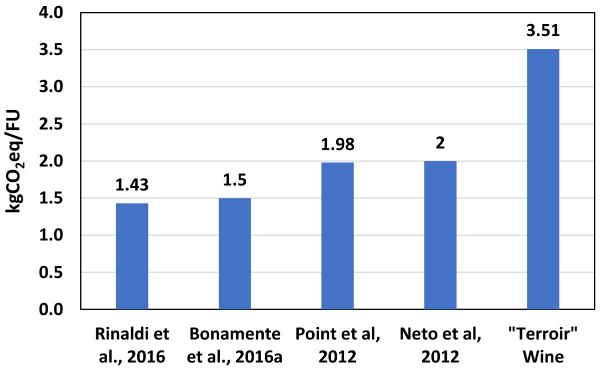

Figure 6. Comparison between the CF of "terroir" wine and values reported in the literature.

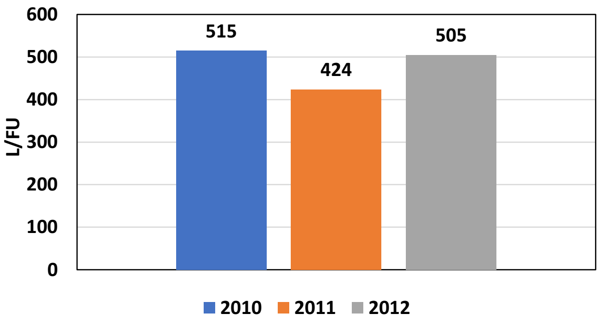

Figure 7. WF for each year considered.

As expected, viticulture has a negative contribution, as carbon is captured during grapes growth. In the remaining life cycle stages, the carbon emissions are positive, being the most representative step, the transportation to retailer. Winemaking, aging in barrels, and bottling, have similar CF, and the least important is bottle storage.

Results show that efforts to reduce the wine CF should focus on reducing the transportation carbon emissions, by either using lower weight packaging or transportation based on renewable energy. The last option is also relevant in the winemaking and bottling stages, as most of the energy used is electricity that could be produced locally, using for example photovoltaic systems. This is shown in Fig. 5 that presents the CF values by scope, where it can be seen the relevance of scope 3, emissions that correspond to the carbon embedded in materials used in the life cycle stages and also transportation. It is followed by scope 2 that corresponds to electricity generation and consumption. Scope 1 includes the direct carbon emissions and carbon capture by the plants that is the dominant term, explaining why it is negative.

Figure 6 compares the average CF of the three production years, with values reported in literature [20,22,28,31,52].

Figure 6 shows that the values obtained for the "terroir" wine are larger than those reported in literature, being the differences mainly attributable to the transportation stage. In most of the literature works, the production volume is smaller, or the transportation distances are smaller, leading to lower carbon emissions. If the transportation stage is removed, the carbon footprint lowers to 1.49 kg CO_2eq/UF, a value within the range of variation of the sample of CF values obtained from the literature.

Figure 7 presents the WF values for each production year considered in this study.

Some differences between the years are observed. Whilst some variability can be attributed to variations in the climatic conditions, in particular to precipitation, a significant difference is due to changes in the viticulture stage, as in 2010 and 2011 no water was spent in irrigation, because the irrigation system was just implemented and firstly used in 2012.

Figure 8 compares the average relative magnitude of each WF term. It can be seen that the green WF (WF_V) is dominant, as expected, since the main source of water for grapes growth is rain water and the water consumed in irrigation is comparatively smaller. Nonetheless, the blue WF (WF_B) is also significant, as plenty of water is spent in the winemaking and bottling operations.

As all the water used in the production processes is treated in a wastewater treatment plant, the main contributor to the grey WF (WF_G) corresponds to the water

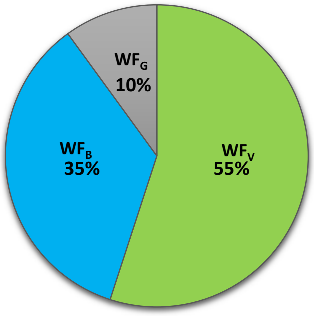

Figure 8. Average relative values of the each WF term.

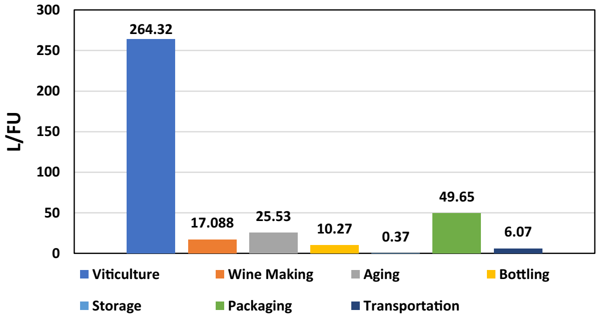

Figure 9. Average values of the WF for each "terroir" wine's life cycle stage.

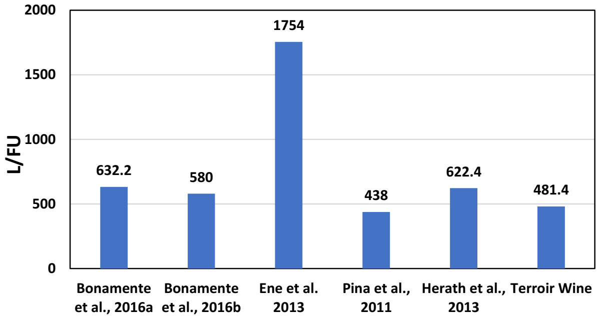

Figure 10. Comparison between the WF calculated in this work with values reported in the literature.

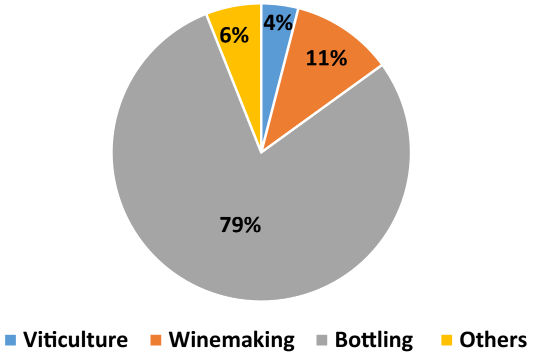

Figure 11. Contribution of each life cycle stage to the material intensity indicator.

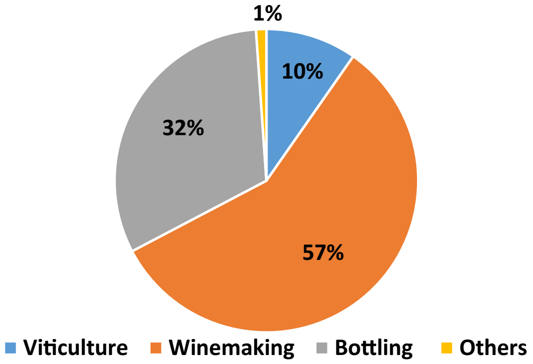

Figure 12. Contribution of each "terroir" wine's life cycle stage to solid waste generated.

embedded in the materials and energy used to produce the "terroir" wine. Results presented in Fig. 8 suggest that a reduction in the water consumed in irrigation, relevant in the viticulture stage, may reduce the green WF. This is confirmed by the results presented in Fig. 9, in which the average values of the WF for each life cycle is compared, showing that the WF of viticulture is the largest one, corresponding to more than half of the total value. For the remaining life cycle stages, packaging is the second largest contributor to the WF, corresponding mainly to the indirect water embedded in the materials used for packaging, as the direct water consumption is smaller, thus justifying the utilization, whenever possible, of materials with lower WF.

A comparison between the calculated values of the WF with values reported in the literature [28,29,52–54] is shown in Fig. 10. A large variability between the values can be observed, result of differences in the life cycle stages, data sources used, wine produced under different climatic conditions and even, different production processes. In general, the WF of the "terroir" wine is smaller than that of other brands, with the exception of the work of Pina et al. [54]. However, those authors analyzed a green wine, whereas in this work a red wine was considered that has a different production process, especially in wine making. Bonamente et al. [29] considered a red wine and obtained larger values for WF but in different climate conditions, in particular with more precipitation, showing that a comparison should be made with caution.

Figures 11 and 12 present, respectively, the indicators of material intensity and solid waste generated. In both figures, the "others" represent all the remaining life cycle stages besides viticulture, winemaking and bottling. Concerning the material intensity, a global value of 0.830 kg/FU was obtained. As expected, the most relevant stage is bottling, corresponding to 79% of the global value.

For solid waste generated, a value of 0.054 kg/FU was obtained. As shown in Fig. 11, winemaking is the most relevant stage, due to the disposed packages of oenological materials used in the winemaking, thus generating more waste.

Table 1 presents the worker turnover rate in percentage values, investment in H&S training (€/FU), and EBITDA expressed as a percentage of the overall company EBITDA, for the three years of 2010, 2011 and 2012. Results show a low value for the workers turnover rate, probably due to worker retirement, and evidencing a good working environment and proper wage retributions, fundamental for the company competitiveness.

The company investment in H&S training is a fundamental aspect to ensure a proper and safe process operation. Concerning the EBITDA, although the "terroir" wine does not contribute significantly to the overall company's EBITDA, its relative importance is increasing

Table 1. Indicators of workers turnover rate, H&S investment, and EBITDA.

Years	2010	2011	2012
Workers turnover rate (%)	4.77	3.46	2.00
Investment in H&S training (€/FU)	0.033	0.028	0.055
EBITDA (%)	0.4	0.7	0.8

in the production years considered. This may be due to an increased interest and value perception of the wine produced in the Douro Valley in recent years.

4. Conclusions

This study examined the sustainability of a Portuguese "terroir" wine produced in the upper valley region, based on sustainability indicators and taking into account its full life cycle, from viticulture to the wine distribution to retailers. Results show that the climatic conditions have a significant influence on the values of the environmental indicators. For the CF, a value of 3.51 kg CO_2eq/FU was obtained, being transportation the most relevant contributor, while viticulture represents a carbon sink with negative CF value. Moreover, the division of the CF by scopes shows that electricity consumption is also a significant factor that can be minimized by using renewable electricity produced locally. An average WF value of 481.4 l/FU was obtained, being viticulture the most relevant life cycle stage. This is expected as the green WF term represents more than 50% of the overall WF mainly due to precipitation and water consumed in irrigation. The values obtained are within the range of values reported in literature. For the materials intensity indicator, bottling is the largest contributor, mainly due to the glass bottles weight, while for the solid waste generated winemaking and viticulture are dominant, mainly due to oenological materials and other products used in both stages. The utilization of lower weight bottles and packages can help reduce both indicators. Concerning the remaining indicators, they evidence a company with good working conditions that invest in the H&S training of its collaborators. Although the EBITDA for the "terroir" wine represents a small fraction of the company overall EBITDA, results show that its importance is increasing.

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