CHEMICAL ENGINEERING TRANSACTIONS

VOL. 57, 2017

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Sauro Pierucci, Jiří Jaromír Klemeš, Laura Piazza, Serafim Bakalis

ISBN 978-88-95608- 48-8; **ISSN** 2283-9216

Sustainability Evaluation of a Portuguese “Terroir” Wine

António A. Martins[a*], Ana R. Araújo[a], Ana Morgado[a], António Graça[b], Nídia S. Caetano[a,c], Teresa M. Mata[a]

[a] LEPABE – Laboratory for Process Engineering, Environment, Biotechnology and Energy, Faculty of Engineering, University of Porto (FEUP), R. Dr. Roberto Frias S/N, 4200-465 Porto, Portugal
[b] Sogrape Vinhos, S.A., Aldeia Nova, 4430-809 Avintes, Portugal
[c] CIETI, Department of Chemical Engineering, School of Engineering (ISEP), Polytechnic Institute of Porto (IPP), R. Dr. António Bernardino de Almeida S/N, 4200-072 Porto, Portugal
amartins@fe.up.pt

This work performed a sustainability evaluation of a Portuguese “terroir” wine, produced in a vineyard inside the Douro Wine Region, based on a Life Cycle Thinking perspective, considering the life cycle stages from viticulture to winemaking, bottling and packaging. Primary data from the company was used as far as possible, complemented with secondary data from life cycle inventory databases, scientific publications and/or reports, and even from tools developed specifically for application in the wine sector. The sustainability evaluation was performed using several indicators, selected based on their relevance to the wine industry, but also considering the existing consensus in the area, including: carbon footprint, water consumption, energy intensity, material intensity, solid wastes and wastewater. Indicators values were calculated relatively to a functional unit of 0.75 L that represents the capacity of most wine bottles available in the market. Results show that bottling and storage have the highest contribution to carbon footprint, material intensity, solid wastes and wastewater. Viticulture is the life cycle stage with the largest contribution to water consumption mainly due to irrigation of vines. Results also show that winemaking is the life cycle stage with the largest contribution to energy intensity, mainly due to the transportation of grapes to the winery and of wine to the bottling facility, accounting for 94 % of this indicator value. Results can be used to identify hotspots in the production process where improvements are necessary or to compare the performance of different wines.

1. Introduction

The wine industry is one of the oldest activities in the agri-food sector. In many regions of the world it is of considerable economic and even cultural importance, being Portugal a good example. Currently, there is a significant increase in the wine production and consumption, with the emergence of new wine producing regions, as for example in China (OIV, 2016). To be successful and competitive, the wine industry is increasingly more interested in improving its contribution to sustainable development and in reporting it. This can be confirmed by the several initiatives to develop and implement guidelines, computational tools and certification schemes to assist wine growers and producers to be more sustainable (Petronilho, 2015). This situation represents not only a challenge but also creates business opportunities and/or competitive advantages, improving the performance of companies and/or wine regions. In view of the various sustainable development initiatives in the wine sector that emerged worldwide, the International Organization of Vine and Wine (OIV) decided to standardize these approaches and incorporate the specific characteristics of the vitivinicultural sector. In its resolution CST 1/2004, OIV proposed the following definition of sustainable winegrowing: “Global strategy on the scale of the grape production and processing systems, incorporating at the same time the economic sustainability of structures and territories, producing quality products, considering requirements of precision in sustainable viticulture, risks to the environment, products safety and consumer health and valuing of heritage, historical, cultural, ecological and aesthetic aspects” (OIV, 2008). Therefore, it is imperative to properly assess the sustainability of the wine and appropriately manage the challenges that its continuing improvement poses. Hence, this work evaluates the sustainability of a Portuguese “terroir” wine throughout the life cycle stages of viniculture, winemaking, bottling and packaging, based on the definition and calculation of adequate sustainability indicators.

2. Methods

2.1 Framework for the sustainability evaluation in the wine industry

When considering sustainability in the wine industry a Life Cycle Thinking (LCT) perspective should be adopted, as it is the proper way to consider all processes that may have a significant impact (Mata et al, 2011, 2013). Currently, sustainability assessment and certification schemes of products and processes, in which agricultural production systems are a key part, are already based on LCT, as for example biofuels (Directive 2009/28/EC). Thus, an objective framework to assess sustainability is necessary, to evaluate the current situation and identify the aspects that can be improved. The framework used in this work is a sequential procedure of interrelated steps, as presented in Figure 1 (Martins, 2007; Mata et al, 2015).

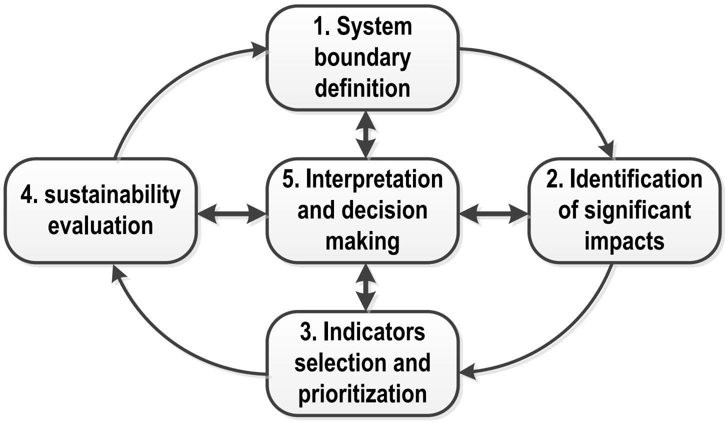

Figure 1: Sustainability evaluation framework.

As shown in Figure 1, the 1st step corresponds to the system boundary definition, in which are defined the life cycle stages that will be considered in the study and the detail in which they will be described depending on the system particularities and study goals. In the 2nd step all the relevant environmental, economic and societal impacts and their relative significance are identified. In that process one needs to study in detail the wine's life cycle stages and to perform a literature review. This procedure is normally supported by the identification of the potential policy or strategic issues, consensual indicators to ensure that decision-making is more robust and less prone to controversy, and an accounting of inputs and outputs (e.g. energy, water, materials, product, by-products, wastewater, gas emissions, and solid wastes, etc.), information from which an educated definition of the indicators can be made. This is akin to a life cycle inventory in life cycle assessment (LCA), although here not just the environmental impacts but also the economic and societal impacts are considered (Mata et al., 2012). From the quantitative and qualitative information gathered, it is constructed the inventory to be used for computation of selected sustainability metrics. The result is a list of indicators directly linked to the product's life cycle. In the 3rd step, indicators deemed appropriate to evaluate the system under study are selected and prioritized based on the information and data gathered in the previous steps. The indicators can be used for decision making, so they need to be correctly defined and calculated to ensure that the most appropriate decisions are taken. In the 4th step, after selecting the indicators they are quantified using data obtained as much as possible from the product or process under study. Only then can product or process alternatives be compared or decisions be made. Finally, in the 5th step decisions are made for improving the product or process based on results of all computed metrics. This framework is robust and has already been applied to a wide range of products or processes (Mata et al., 2014, 2015).

2.2 System boundary definition

The "terroir" wine of this study grows in a vineyard of about 156 ha located in the Douro's valley in the North of Portugal. Figure 2 shows the system boundary considered for this study. Viticulture includes practices, such as preparing the vineyard, pruning and modulating the growth of the vines, utilization of fertilizer and phytochemicals, and irrigating whenever necessary. For winemaking, grapes are harvested in the vineyards adjacent to the winery. The grapes are registered upon arrival to the winery, weight and grape variety being recorded. A sample of juice is then analysed to determine the sugar content (which gives a measure of the probable or theoretical alcohol content of the resulting wine), volumic mass, pH and titratable acidity. On site, the reception of grapes is done using hoppers that convey them to crushers/ destemmers. The grape stalks, resulting from the destemming operation, are composted and used as fertilizer (by-product) in the same vineyard. The crushed grapes are sent to fermentation tanks. For fermentation, oenological products (tartaric acid and yeasts) are added to the must. Tartaric acid lowers pH to about 3.6 to 3.7. SO_2 is added to the must to prevent oxidation and development of undesirable bacteria and yeasts. Fermentation takes about 6 days on average, after which the wine (liquid) is separated from the marc (solid) by pressing. The pressed marc is sold to produce brandy and other wine spirits (by-product). The wine produced is stored in stainless steel vats for a few days and then, it is transported in tanker trucks to warehouses (located in other installations) where it is stored in barrels for about one year of aging period before it is bottled. After the aging period, the wine is transported to be bottled in another plant.

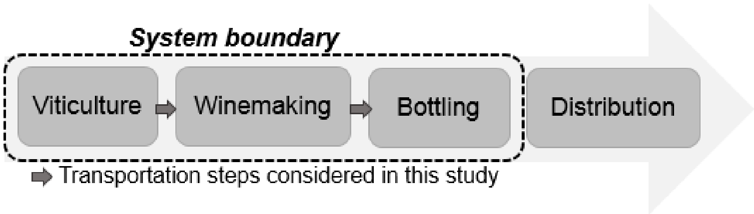

Figure 2: System boundary definition including the wine's life cycle stages considered for the study.

2.3 Functional unit

The functional unit selected for this work is 0.75 L that represents the main used capacity of market-available wine bottles, allowing for a more objective comparison between different types and/or brands of wine.

2.4 Reference years

Climatic conditions have a strong influence on wine production, both in terms of quantities as well as quality. They can have as significant influence on the environmental impacts (Vázquez-Rowe et al., 2012). To minimize this source of variability, the data from three consecutive years was used. Thus, for the "terroir" wine that needs to have a barrel and bottle aging period, the chosen bottling years were 2012, 2013 and 2014, considering that the fermentation of the wine occurred during 2010, 2011 and 2012, followed by an aging period of one year. The average values of these three reference years were used in the calculation.

2.5 Indicators Selection

The evaluation should be based, as much as possible, on quantitative measures or indicators. This way, it is possible to have a better idea of the current situation in terms of sustainability, identifying which aspects should be improved, and manage and support decision making, facilitating the definition of effective strategies and/or policies and support decision-making. The indicators or metrics should take into account the environmental, economic, and societal dimensions of sustainability, and selected according to their significance to the wine sector and stakeholders. Although there is some freedom in their selection, some rules should be followed to ensure that the most adequate indicators are selected (Martins et al., 2007). In particular, the set of indicators should be as small as possible, and the indicators should be simple and easy to calculate, consensual and independent of each other, unbiased, representative of the product or process system and directly related with key aspects of sustainability. For this study, the indicators selected took into account the information available in the literature, concerning the sustainability initiatives in the wine sector, studies published in the open literature, data and goals of the wine producing company. Although there are some efforts to consider the social and cultural aspects, in most cases, only environmental and economic indicators were taken into account, as they are much easier to quantify. Thus, the selection set considered for this study includes the following sustainability indicators: energy intensity (MJ/0.75 L), carbon footprint (kg CO_2 eq. /0.75 L), Water consumption (L/0.75 L), material intensity (kg/0.75 L), solid wastes (kg/0.75 L) and wastewater (L/0.75 L). Energy intensity and carbon footprint are both consensual indicators (Rugani et al, 2013; Mata et al., 2015) and they can be used for marketing purposes to inform consumers (Vázquez-Rowe et al., 2013). They quantify the process energy efficiency and the greenhouse gas emissions respectively, which are relevant from an economic and societal point of view, since energy costs are increasing and the consequences of climate change are more evident nowadays. The remaining indicators are directly related to the specific product and processes analysed, assessing the process efficiency and potential environmental impact. They are also pertinent from an economic point of view, as raw materials and waste processing normally represent a cost. Regarding the chosen environmental indicators, they are consistent with the recommendations given in the available Product Category Rules, as proposed to develop the Environmental Product Declarations (EPD) for specific brands of wine (Life HAproWINE, 2013; Envirodec, 2015) and published guidelines for sustainable wine growing (CAWG, 2012).

2.6 Inventory analysis, data sources and calculations

The data used for the inventory analysis regarding the core processes of viticulture, wine production, bottling and packaging were gathered in the Portuguese wine producing company (primary data) and completed with data from literature and commercial life cycle databases (secondary data). The winery that produces the "terroir" wine also produces other brands of wine. Thus, an allocation procedure was necessary since the data supplied by the company is aggregated for all the wines produced in the winery. This way, since the wine making process is very similar between wine brands, by knowing the total volume of wine produced at the winery and that of the "terroir" wine a simple proportional allocation was performed. The indicators of water consumption, material intensity, wastewater and solid waste were obtained using only primary data provided by the company. For calculating the energy intensity indicator it was used data provided by the company on the consumption of electricity and natural gas. To estimate fuel consumption in the transportation of grapes to fermentation and of wine to bottling, it was used secondary data from Life Cycle Inventory databases and average values of fuel consumption in heavy-duty vehicles in Europe. For the carbon footprint estimation, carbon dioxide emissions related to the consumption of electricity and natural gas were obtained directly from invoices provided by the company. For the calculation of remaining emissions secondary data obtained from databases and information available in the literature were collected. Therefore, the following data sources were used: (1) Primary data: company bills; data provided by the company; (2) Secondary data: EcoInvent V3 available with SimaProTM 7.3 software; International Wine Carbon Calculator (IWCC, 2017); US Environmental Protection Agency (US EPA); other data published in the literature. After gathering all data and information needed for the study, they were treated and allocated to the wine under study. Then, indicators values were calculated in relation to the functional unit (0.75 L of wine).

3. Results and Discussion

In this section, the results of the sustainability indicators calculation are presented and discussed. Table 1 shows the indicators values for each life cycle stage.

Table 1: Sustainability indicators for each wine's life cycle stage

Indicator	Viticulture & transportation	Winemaking	Bottling & storage	Total
Carbon footprint (kg CO_2 eq./ 0.75 L)	0.1049	0.2962	0.9313	1.3304
Water consumption (l/0.75 L)	17.440	0.4280	1.1497	19.0178
Energy intensity (MJ/0.75 L)	2.3700	4.2250	0.2450	6.8400
Material intensity (kg/0.75 L)	0.0260	0.0948	0.6525	0.7733
Solid waste generation (kg/0.75 L)	0.0052	0.0030	0.0170	0.0252
Wastewater (l/0.75 L)	0.0000	0.3110	1.0000	1.3110

The carbon footprint considers emissions from several sources, such as production and transportation of fertilizers, phyto-pharmaceuticals, materials used in vineyard maintenance, electricity, fuels and agricultural practices. The carbon absorbed by the vines during their growth (of -0.50 tons of CO_2 eq./hectare) was subtracted to account for the short-term carbon cycle emissions, estimated using V1.3 of IWCC (2017). For electricity, an emission factor of 0.440 kg CO_2 eq./kWh was considered. For diesel fuel and gasoline the carbon emission factors considered were respectively 0.0741 and 0.0693 kg CO_2 eq./MJ fuel. For fertilizers, an emission factor of 0.00909 kg CO_2 eq./L. For transportation of grapes from the vineyard to the winery a carbon emission factor of 0.891 kg CO_2 eq./tkm and the average distance of 1.63 km as the vineyard is located adjacent to the winery. For transportation of wine from the winery to the bottling unit it was considered a carbon emission factor of 0.133 kg CO_2 eq./tkm and the average distance of 230 km. For phyto-pharmaceuticals was considered an emission factor 10.1 kg CO_2 eq./kg obtained from the EcoInvent V2.1 database integrated in the SimaPro^{TM} 7.3 software. For the materials used in the vineyard, the emission factors of 74.7 kg CO_2 eq./m^3 material and 1.8 kg CO_2 eq./kg steel were considered depending on the type of materials used. Concerning the carbon emissions from agricultural practices, in particular those related to land preparation, this study considered it to be zero due to the lack of data available for the Douro valley region in the north of Portugal. Also, the emission factor available for it in the International Wine Carbon Calculator V1.3

(IWCC, 2017) is not representative of the practices in this Portuguese region, which have a schist and arid soil with very low carbon content.
Figure 3 shows the relative percentage in which each stage of the wine life cycle contributes to the sustainability indicators.

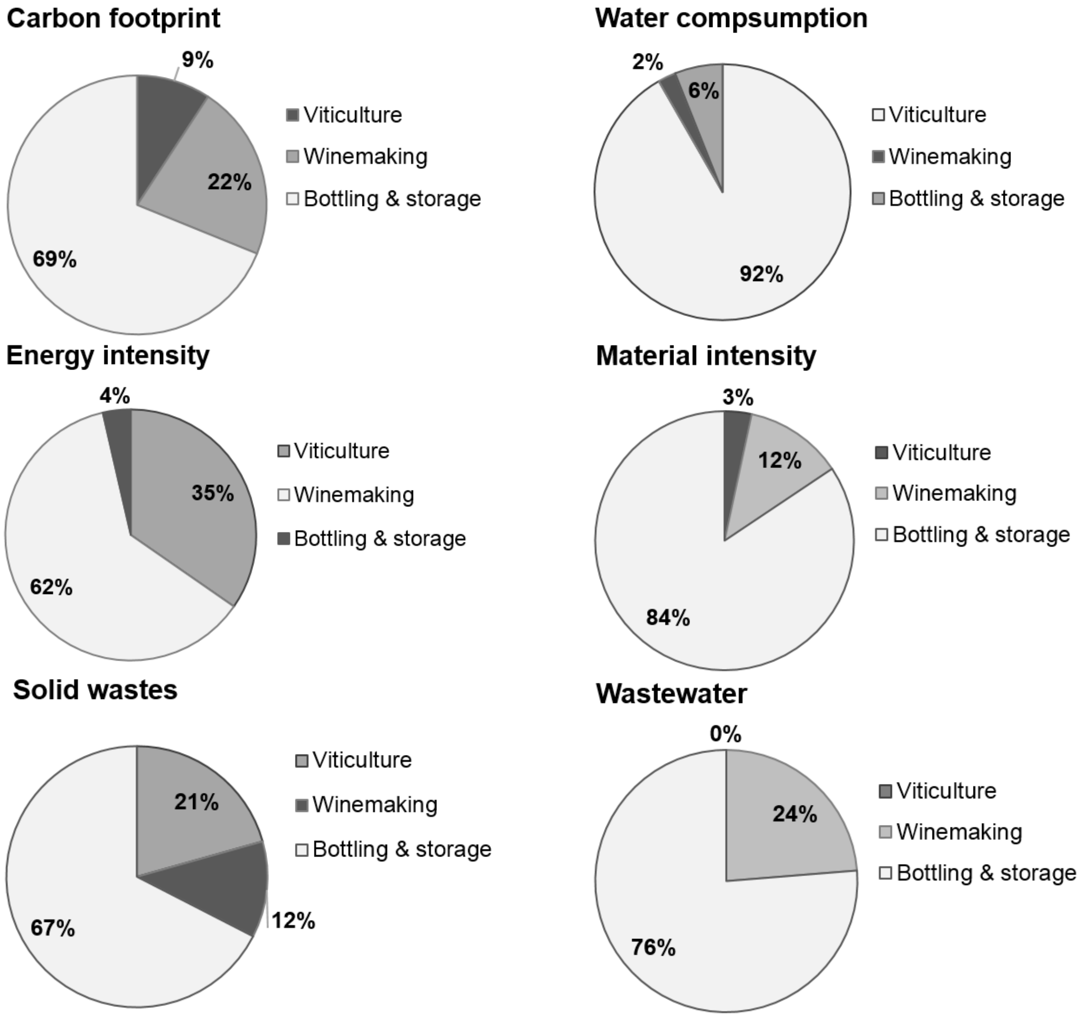

Figure 3: Comparison of the relative percentage in which each stage of the wine life cycle contributes to the sustainability indicators.

Results show that bottling and storage have the highest contribution to the indicators of carbon footprint, material intensity, solid wastes and wastewater. Viticulture is the life cycle stage with the largest contribution to Water consumption mainly due to irrigation of vines, although in this study it was done irrigation only on the reference year 2012, because in 2010 and 2011 the irrigation system was not yet installed in the vineyard. Water from rainfall was is not accounted in the water consumption indicator for irrigation. This is expected as worldwide, agriculture accounts for 70 % of all water consumption, compared to 20 % for 2012 industry and 10 % for domestic use (http://www.worldometers.info/water/). Results also show that winemaking is the life cycle stage with the largest contribution to energy intensity, mainly due to the fuel consumption in the transportation of grapes to the winery and in the transportation of wine to the bottling facility, which summed account to 94 % of this indictor value, corresponding to 3.99 MJ of fuel per 0.75 L of wine. The material intensity indicator considers the materials used in the vineyard (e.g. fertilizers and phyto-pharmaceuticals), in the winery (e.g. oenological products, oils and lubricants and hygiene products) and in the bottling facility (e.g. bottles, labelling and packaging materials). As expected, bottling is the life cycle stage with the largest contribution (84 %) to the material intensity indicator due to the amount of packaging materials consumed, mainly glass bottles, since this indicator is measured as kg/functional unit. In the same way bottling is the life cycle stage with the largest contribution (67 %) to the solid wastes indicator. Concerning the wastewater, bottling is the life cycle stage with the largest contribution (76 %) mainly due to the bottles flushing and cleaning of equipment in the bottling facility. The comparison with other published wine-related LCA studies cannot be done directly due to differences in system boundary definitions and assumptions. For example, in this study the external transportation of grapes and wine is accounted as part of the winemaking step. In other studies, external transportation is not accounted for (Vàzquez-Rowe et al., 2012) or it is accounted as part of other life cycle steps, such as grape production or viticulture (Bosco et al., 2011).

4. Conclusions

This study evaluated the sustainability of a Portuguese “terroir” wine based on chosen sustainability indicators, mainly covering the environmental dimension of sustainability. This work allows the company to better streamline its production chain to increase its global sustainability, while aggregating value for all the involved stakeholders, most especially the final consumer. Possible measures to minimize environmental impacts include the reduction of water and energy consumption to be implemented after specific water and energy audits.

Acknowledgments

Authors thank the financial support of project PP-IJUP2014-SOGRAPE funded by Sogrape Vinhos, SA and of project POCI-01-0145-FEDER-006939 (Laboratory for Process Engineering, Environment, Biotechnology and Energy – LEPABE) funded by FEDER through COMPETE2020 - Programa Operacional Competitividade e Internacionalização (POCI) and by national funds through FCT. Authors also thank FCT for their support through provision of the research grants IF/01093/2014 and SFRH/BPD/112003/2015.

References

Bosco S., Di Bene C., Galli M., Remorini D., Massai R., Bonari E., 2011. Greenhouse gas emissions in the agricultural phase of wine production in the Maremma rural district in Tuscany, Ital. J. Agron. 6:e15, 93-100.

CAWG, 2012, California code of sustainable winegrowing workbook, A project of the California Winegrowing Alliance, Wine Institute and California Association of Winegrape Growers (CAWG).

Directive 2009/28/EC on the promotion of the use of energy from renewable sources, Commission of the European Communities.

Envirodec, 2015, Product Category Rules: Wine of fresh grapes, except sparkling wine; wine must, UN CPC 24212 <http://www.environdec.com/> accessed 12.04.2016

IWCC, 2017, International Wine Carbon Calculator <https://fivs.org/wm/strategicInitiatives/fivsForesee.htm>

Life HAproWINE, 2013, Product Categories for wine <http://www.haprowine.eu/documentacion_e.html>

Martins A.A., Mata T.M., Costa C.A.V., Sikdar S.K., 2007, Framework for sustainability metrics. Industrial and Engineering Chemistry Research 46 (10), 2962-2973.

Mata T.M., Caetano N.S., Martins A.A., 2015, Sustainability evaluation of nanotechnology processing and production, Chemical Engineering Transactions 45, 1969-1974, DOI: 10.3303/CET1545329.

Mata T.M., Martins A.A., Neto B., Martins M.L., Salcedo R.L.R., Costa C.A.V., 2012, LCA tool for sustainability evaluations in the pharmaceutical industry. Chemical Engineering Transactions 26, 261-266, DOI: 10.3303/CET1226044.

Mata T.M., Martins A.A., Sikdar S.K., Costa C.A.V., 2011, Sustainability considerations of biodiesel based on supply chain analysis, Clean Technologies and Environmental Policy, 13, 655-671.

Mata T.M., Mendes A.M., Caetano N.S., Martins A.A., 2014, Sustainability and economic evaluation of microalgae grown in brewery wastewater, Bioresource Technology 168, 151-158.

Mata TM, Martins AA, Sikdar S, Costa CAV, Caetano NS., 2013, Sustainability Considerations about Microalgae for Biodiesel Production. In: Lee, J.W. (Ed.), Advanced Biofuels and Bioproducts, Springer, pp. 745-757.

OIV, 2008. Guidelines for Sustainable Vitiviniculture, OIV Resolution CST 1/2008.

OIV, 2016. World Vitivinicultural Situation 2016. Organisation Internationale de la Vigne et du Vin (OIV), Paris.

Petronilho, S.L., 2015, Sustainable viticulture in Bairrada appellation: vineyard and harvest year effects on grapes oenological potential; PhD thesis, University of Aveiro, Portugal. http://hdl.handle.net/10773/14101

Rugani B., Vázquez-Rowe I., Benedetto G., Benetto E., 2013, A comprehensive review of carbon footprint analysis as an extended environmental indicator in the wine sector, J Clean Prod 54, 61-77.

Vázquez-Rowe I., Rugani B., Benetto E., 2013, Tapping Carbon footprint variations in the European wine sector, J Clean Prod 43, 146-155.

Vázquez-Rowe I., Villanueva-Rey P., Moreira M., Feijoo G., 2012, Environmental analysis of Ribeiro wine from a timeline perspective: Harvest year matters when reporting environmental impacts, J Environ Manage 98, 73-83.