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Life Cycle Assessment in the Agri-food Sector

Case Studies, Methodological Issues and Best Practices

Rete Italiana LCA

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Contents

Chapter 3
Life Cycle Assessment in the Wine Sector

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Abstract Currently, stakeholders' increasing attention to quality is driving the wine sector to rethink and change its own production processes. Amongst product quality dimensions, the environment is gaining ever-growing attention at various levels of policy-making and business. Given its soundness, the use of Life Cycle Assessment (LCA) has become widespread in many application contexts. Apart from applications for communication purposes, LCA has also been used in the wine sector to highlight environmental hot spots in supply chains, to compare farming practices and to detect improvement options, *inter alia*. Case studies whose focus is the wine industry abound in high quality publications.

This Chapter has a two-fold focus: firstly, an analysis of the methodologies and standards of the Life Cycle Thinking concept, related to wine, and secondly, a

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critical analysis of wine LCA case studies in order to compile a list of scientifically-based environmental hot-spots and improvements.

The chapter also expands the knowledge on LCA's application to the wine industry by discussing how best to contribute to:

- the identification of the critical environmental issues of the wine supply-chain and the essential elements that an LCA case study in the sector should consider;
- the identification of an optimal set of indicators and methodologies for the evaluation of the environmental impacts of wine;
- the comparability of results;
- the improvement of the environmental research quality in this sector.

Keywords Life cycle assessment · Wine · Life cycle-based tools · Life cycle-based methodologies · Case-studies

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3.1 Introduction

3.1.1 Background

3.1.1.1 Nutritional, Cultural and Functional Aspects

The origins and history of the beverage obtained by the fermentation of grapes are strongly linked to those of European people and their civilisations. Indeed, even before the Bible, the civilisations of the Middle East knew the beverage and they considered it as a gift from the gods to those who had founded their society (Austin 1985). Even in Ancient Greece, the religious mystical concept of wine (as a means of communication with the gods) appears early on in the conceptions of Homer and Plato, who see it as a pleasure to be enjoyed slowly (Austin 1985). Plato himself repeatedly stresses the importance of social drinking during feasts; wine is also an essential element in the original Socratic method of seeking the truth in a group (Austin 1985). It is worth mentioning that no one ever saw Socrates drunk, although he could outdrink anyone.

From the Middle Ages until about 1600, the consumption of wine declined in favour of beer (Babor 1986); this was because of the costs of production (beverages obtained from cereal crops were cheaper).

The development of viticulture and the availability of wine at affordable prices were welcomed by the Mediterranean populations, who had never given up completely on the most beloved and traditional of beverages. In fact, the conviction that "good wine makes good blood" became proverbial, "blood" having a double meaning: physical, as it nourishes the organs, and mental, influencing behavioural attitude and disposition (mood).

In fact, wine is often considered not just as food in the popular tradition but as a medicine. Although not specific to certain diseases, it is nonetheless applicable to the replenishment and renewal of one's strength (a "tonic" or "restorative", ignored by mainstream medicine) and in general to the recovery and maintenance of well-being. The link between wine and health, and the positive effect of the regular consumption of wine (albeit in moderate amounts) received sensational affirmation between 1980 and 1990 from the medical profession in the form of the "French Paradox" (Leger et al. 1979). Statistical and epidemiological investigations documented a reduced incidence of cardiovascular diseases and relative complications in some regions of southern France, in spite of the high consumption of atherogenic fats (Leger et al. 1979). This was in sharp contrast to the high impact of these diseases in other European and North American populations, who consumed equivalent amounts of the same fats. The difference was attributed to the habitual consumption of wine by the French as a protective factor against atherosclerosis and the atherosclerotic cardiovascular damages related to it. Numerous researchers (Rimm et al. 1996; Kauhanen et al. 1999; Criqui and Ringel 1994; Artaud-Wild et al. 1993; Nigdikar et al. 1998) believe there is a negative correlation between moderate consumption of red wine (one to two glasses per day) and coronary heart disease; however, the question is not entirely clear.

Table 3.1 Main constituents of wine. (Source: Cozzani 2005)

Constituents	Quantity (g/l)
Water	750–900
Ethyl alcohol	70–130
Methyl alcohol	0.02–0.2
Higher alcohols	0.1–0.5
Glycerol	4–15
Sugars	Traces in dry wines
(Glucose and fructose)	Varying amounts in sweet wines
Tartaric acid	2–5
Malic acid	0–7
Citric acid	0.1–0.5
Succinic acid	0.5–1.5
Lactic acid	1–5
Acetic acid	0.2–0.9
Phenolic compounds (tannins, etc.)	0.2–3
Nitrogen compounds	0.05–0.9
Minerals (such as ash)	2–3

Brief Review of the Main Constituents The chemical components of wine number several hundred, but common chemical analyses determine only the main constituents, which are useful for characterising the product from a commodity perspective and verifying its compliance with legal regulations, quality classifications and related disciplines. Table 3.1, which summarises the main chemical components of wine, shows that wine does not provide considerable amounts of any of the major nutrients: neither protides (proteins, peptides, amino-acids), nor lipids (fats, oils), nor glycides (simple or polymeric sugars), with the exception of sweet wines. The vitamin-related content of wine is almost negligible. The only components which can be regarded as important for both nutrition and health are alcohols and in particular ethanol (or alcohol/spirit or ethyl alcohol by definition), which is present in wine at average concentrations of 10 % (weight/volume).

3.1.1.2 The Wine Supply Chain

World wine production in 2012 was lower compared with the previous year, declining by about 10 % and reaching 252 Mhl of wine produced (OIV 2013). Consumption now appears to be stable at about 243 Mhl, despite a significant decrease in taxes in some countries (OIV 2013). Nevertheless, in recent years, the wine industry has been affected by continuous changes in terms of technology, product quality and consumer requirements. In this dynamic environment, European countries certainly remained the principal actors, accounting for 64 % of world production (OIV 2013).

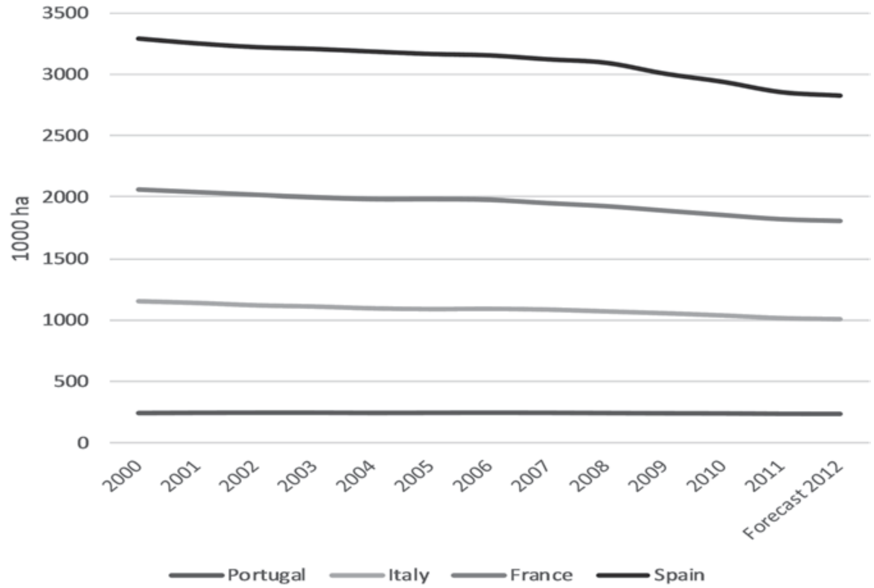


Fig. 3.1 Decline in vineyards of major European wine producers. (Adapted from: OIV 2013)

On the other hand, with regard to international dynamics, France is the clear leader in terms of value of goods exported, and Italy predominates in terms of quantities and volumes exported, followed by Spain.

The world trade has grown dramatically, reflecting a consumption of wine that is no longer merely local. It brings together the "old producers" with the new world of wine, which includes the United States, Australia, Argentina, Chile, New Zealand and South Africa, thus creating a new competitive structure.

As regards the area covered by vineyards worldwide, estimates prepared by the OIV (International Organisation for Vine and Wine) show a slowing-down in the sector (OIV 2013). That report shows a decrease for the year 2012 in territories occupied by vineyards (see Fig. 3.1). Vineyards covered an area of about 7528 Mha worldwide in 2012, including those not yet producing or harvested. Although there is a slight decline in the years 2011–2012, this is still lower than in previous years.

As regards the regulation about the production and sale of wine, the OIV establishes the general principles to which every state should refer, but national regulation may vary from country to country. With regard to the terminology adopted, every state that produces grapes or wine generally incorporates the definitions set by the OIV. Specifically, wine is defined (OIV 1992) as "the beverage resulting from full or partial alcoholic fermentation of fresh grapes, whether crushed or not, or of grape must. Its actual alcoholic strength may not be less than 8.5% vol. However, considering the conditions of the climate, the terroir and the grape variety, quality factors of special or particular traditions of some vineyards, the minimum total alcoholic strength may be reduced to 7% vol. according to the specific regulations of the region concerned" (OIV 1992).

As regards the designation of origin and geographical indications, it is the OIV that defines the application rules and keeps a list of the same. The principle is enshrined in Resolution ECO 2–92 (OIV 1992) which recognises designations of origin and geographical indications. The product "wine" is the result, regardless of the designation of origin or geographical indication, of a number of stages that can be grouped into the following broad categories:

- agricultural phase
- vinification and distribution phase

Agricultural Phase The vine is a long-lived shrub (50–70 years in some cases). There are cases of vineyards (e.g., in Maribor, Slovenia) that were planted about 400 years ago but still produce very low quantities of grapes. When it comes to LCA, the agricultural phase has been frequently simplified in the literature, taking into account only the year(s) of actual grape production for quantifying input requirement and the release of emissions. Yet it is important to consider the overall life cycle of a vineyard, including its planting, the first unproductive years, the productive years and then senescence and disruption, as in the case of every perennial crop (Marenghi 2005).

Every new vineyard planting is characterised by the work needed for the preparation of the soil. The first stage concerns the physico-chemical analysis of the soil, which determines all the main indicators of the soil (texture, organic matter, pH, nutrient deficiencies). A preliminary analysis of soil characteristics, along with the knowledge of the climatic condition of a territory, allows technicians to choose the cultivars best suited to the area and decide which precautions should be taken during the first planting. These preliminary steps must also consider the plantation density (number of plants per hectare), which ranges from 1500 to 10,000 vines per hectare. The planting density will affect the intensity of treatments for pest management and the harvest costs. The planting needs deep tillage in order to allow the root system to grow unimpeded. After that, vine support is performed. The vine, being a climbing plant, requires a supporting infrastructure; these may be structures with stakes of wood, concrete or metal. Afterwards, vine cuttings can be planted. The vine needs two or three years to start producing grapes. During this period, the vineyard management is fully operative; fertilisation, pesticide treatments and soil management, with the exclusion of harvest, are needed. The vineyard grape yield grows for the first six to eight years and then stabilises. Vineyard management in the productive years is strongly dependent on the microclimate of the area, the characteristics of the soil, the field slope and grape quality. Pruning is usually carried out both in wintertime and in spring. Weed management can be performed by mechanical weeding or by chemical weeding; pest control is crucial in vineyard management to prevent attacks by pathogens and consequent reduction in grape quantity and quality. When the grapes reach optimal maturity (in terms of sugar level, level of acidity, and colour) they are collected through manual or mechanised processes (mechanical harvester), and then they are conveyed into trailers and transported to the winery for vinification. Grapes cannot be stored because of decay-related problems, so the process of vinification must be initiated immediately (Reynier 2011).

Vinification and Distribution Phases Once the grapes arrive at the winemaking facilities, all the quality parameters of the product are controlled and the phase of vinification can start. Each bunch of grape is deprived of the stem (in order to avoid problems of fermentation and tannic flavours) (Ribéreau-Gayon and Peynaud 1979) and pressed to promote the fermentation of the entire mass. The must is pumped into fermenters (fermentation tanks), where yeast is added and fermentation occurs whereby sugars are converted into alcohol and carbon dioxide. During this phase, an exothermic reaction takes place causing the temperature to increase, usually between 26 and 30 °C. Control of the reaction temperature affects the quality of wine to a significant degree (especially white wines); this operation thus entails the highest energy consumption in the vinification process. However, the fermentation process can differ depending on the type of wine. For example, in the case of red wine the must is fermented with the skins, whereas for white wine skins are removed.

When the entire sugar component has been transformed, the wine is separated from the skins. This process can be performed by different techniques (draining, pressing, etc.) and allows wine to be obtained, which is then transferred for ageing. These techniques include:

- the formation of homogeneous masses required for large volumes of wine in order to ensure a uniform quality standard;
- the ageing in casks or barrels, intended primarily for small quantities of valuable wine (because of the high cost).

When winemakers deem that the product is suitable for the market, the wine can either be sold in bulk, i.e. without any type of packaging, or be bottled and packaged before distribution to retailers or end consumer.

3.1.1.3 Main Environmental Problems

The wine industry is a productive activity and, as such, cannot be considered environmentally impact-free. For example, the phase of agriculture in the wine life cycle can generate a remarkable impact on climate change (Arzoumanidis et al. 2013a; Pattara et al. 2012a; Petti et al. 2010a), which is caused by the use of fossil fuels for cultural practices, pesticides and herbicides used for crop protection and fertilisers applied to maintain high yields. Nonetheless, the industrial phase also imposes environmental loads that cannot be ignored in the framework of an overall assessment of the life cycle of wine. What follows is a summary (by no means exhaustive) of the main environmental issues related to the life cycle stages of wine. The impact categories and related indicators enumerated below are analysed in Sect. 3.3:

- Land use and land use change. These land-based indicators can be effective for the impact assessment of the vineyard plantation, as the land was previously used for other crops or forest and may be used for purposes other than wine production after the dismantling of the vineyard.

- Climate change. It is well known that climate change is related to the emission of greenhouse gases (IPCC 1997) generated by the use of machinery in the agricultural phase and during the industrial production of electricity consumed in the winemaking process.
- Ozone depletion. The reduction of the ozone layer is caused mainly by chlorine and bromine, which are contained in many substances and compounds. Amongst these, refrigerant gases can be identified, which were used until the 1980s for temperature control in the winemaking process (industrial refrigerators). Currently, CFCs and HCFCs are banned by the EU (Reg. CEE 3952/92). However, it is still possible to find them as refrigerants in old structures.
- Photochemical ozone formation.
- Resource depletion. Water consumption in the wine production process is related to the agricultural phase (use of water for plant protection treatments, irrigation) and in the industrial phase (washing of fermentation and storage tanks); other renewable resources such as wood and cork, and non-renewable ones, such as fossil fuels and minerals, are also directly and indirectly consumed in the wine life cycle.
- Eutrophication. The fertilisers used in the field are not completely absorbed by the roots of the plants, and as a result of atmospheric precipitations they leach into surface- and groundwater. This is one of the most significant impact categories in wine production.
- Acidification. This impact category refers to all the factors that contribute to the reduction of the pH of the soil or water. Acidification may be caused by the emission into the atmosphere or the release into the soil of precursor compounds (e.g. NO_x, SO_x, NH_3).

3.2 Life Cycle Assessment Methods for Measuring and/or Communicating the Environmental Performance of Wine and Wineries

As mentioned in Sect. 3.1, the environmental relevance of the wine sector has been growing over the last decades, rendering it an important contributor to a series of environmental impacts (see e.g., Arzoumanidis et al. 2013b).

The environmental performance of wine has been thoroughly examined in an array of LCA case studies (see Sect. 3.3). In this Section, methodologies that are based on the life cycle thinking concept and that are related to the wine sector are characterised. These methodologies can be divided into two categories: (1) those which are product-related and (2) those which are organisation-related.

The life cycle methodologies at the product level that were identified and that will be analysed in detail are (last update in July 2013): (1) product category rules (PCRs) issued by the International Environmental Product Declaration (EPD) system; (2) the Beverage Industry Sector Guidance for GHG Reporting; (3) the Sustainability Consortium methodology; (4) Sustainability Assessment Methodology for Wine (Italian Ministry for the Environment, Land and Sea); (5) the OIV (Organisation Internationale de la Vigne et du Vin) GHG Accounting Protocol for the Vine and Wine Sector.

On the other hand, methodologies at the organisation level comprise: (1) the OIV GHG Accounting Protocol for the Vine and Wine Sector; (2) the Joint Research Centre's (JRC) low carbon farming practices methodological guidelines; (3) the Beverage Industry Sector Guidance for GHG Emissions Reporting by the Beverage Industry Environmental Roundtable.

The methodologies were thoroughly characterised and analysed in order to provide an overview of the methodological specifications addressed both at product and at organisation level. This detailed analysis may facilitate the harmonisation of the assessment rules and act as a stepping-stone towards consolidation of environmental assessment methods. This would be useful also for delivering some insightful information regarding the "lessons learnt", as discussed in Sect. 3.4.

As a first step, the methodologies were characterised using the template developed and collectively agreed at the world level in the framework of the PCR Development Initiative (PCR Development Initiative 2013). The analysis thus included aspects as follows:

- General information: name of the methodology, date of expiration, product category, standards conformance, etc.
- Goal and scope: functional unit, system boundaries, data quality requirements, etc.
- LCI: primary and secondary data collection requirements, requirements regarding allocation, etc.
- LCIA: impact indicators, justification for their selection.

As well as what is in the PCR template, methodologies were also screened to identify what are considered as co-products, by-products and waste streams.

To this end, the identified methodologies were examined and separate characterisation sheets were produced for each one of them.

It must be noted, however, that the Italian Sustainability Assessment Methodology for Wine (Sustainability in the Italian Viticulture 2014) and the methodology developed by the Sustainability Consortium (TSC 2014) were excluded from this study, because they were not publicly available at the time of the review.

Finally, a brief description of simplification in LCA and simplified LCA tools is outlined in Subsection 3.2.3.

3.2.1 Brief Description of the Methodologies and Standards

In this section, the various methodologies identified are briefly presented for organisation and product level.

The International EPD® System Two methodological guidelines were identified as relevant for this review: (1) PCR of wine of fresh grapes, except sparkling wine;

grape must (EPD 2013, 2010:02) and (2) PCR of packaged sparkling red, white and rosé wines (in any kind of container and closure system) (EPD 2006, 2006:03). These methodologies, which are both at the product level, were issued by the International EPD® System (ENVIRONDEC 2014). The International EPD® system, which is based on international standards such as ISO 9001, ISO 14001, ISO 14040, ISO 14044, ISO 14025, ISO 21930, is one of the organisations supporting the development, release and update of PCRs. These PCRs provide, amongst other things, product-specific rules ranging from goal and scope definition to minimum data quality requirements for LCA studies instrumental to EPDs®, business-to-business shaped environmental communication systems according to ISO 14025 (EPD 2006; EPD 2013). In this context, supporting LCA studies are conducted with the attributional data modelling approach (De Camillis et al. 2013); see also Sect. 3.3.

Beverage Industry Sector Guidance for Greenhouse Gas Emissions Reporting The Beverage Industry Environmental Roundtable issued the second version of the Guidance for Greenhouse Gas Emissions Reporting in 2010 (BIER 2010), both at an organisation and at a product level. The overall aim of this roundtable, which was founded in 2006, is to identify ways to reduce water use, energy consumption and GHG emissions across the value chains of associated organisations and across the life cycles of products of the beverage sector (BIER 2010, p. ii). The specific objective of the guidelines under study is to estimate, track and report GHG emissions within the beverage industry.

The Sustainability Consortium The Sustainability Consortium (TSC) is an organisation that aims at developing methodologies, tools, and strategies to drive a new generation of products and supply networks that address sustainability-related issues about particular product categories (TSC 2014). Wine-specific and fruit-specific (thus including grapes) guidelines at the product level are under development by the TSC. These will also be used to derive key performance indicators to be used by retailers to classify wineries.

The OIV GHG Gas Accounting Protocol for the Vine and Wine Sector The International Organisation of Vine and Wine is an intergovernmental body, the aim of which is, amongst others, to contribute to harmonising existing technical documents and practices as well as to exploring the chance to proactively develop new technical specifications from the very beginning (OIV 2014). Being a sector-specific organisation, the OIV acknowledges the necessity of harmonising the international existing GHG accounting standards (for instance, the International Wine Carbon Protocol, the ISO 14040, 14044 and 14064 standards and others) in the vine and wine sector. For this reason, OIV issued the GHG Accounting Protocol for the Vine and Wine Sector in 2011 (OIV 2011), focusing on both the organisation and the product level.

The JRC Low Carbon Farming Practices Methodological Guidelines The Institute for Environment and Sustainability of the Joint Research Centre (JRC) of the European Commission along with Solagro, a non-profit organisation based in France, issued a set of guidelines for enhancing low carbon farming practices in 2013

(Bochu et al. 2013). The GHG emission measurement tool, called the "Carbon Calculator", calculates emissions at farm scale and delivers results at the organisation level for a reporting period of one year. The guidelines underpinning the Carbon Calculator are based on ISO 14044 and European reference methods (i.e. the Organisation Environmental Footprint Guide and Envifood Protocol). The JRC supported the development of this tool in response to the European Parliament's request for a project on the certification of low carbon farming practices in the EU.

The Sustainability Assessment Methodology for Wine The Italian Ministry for the Environment, Land and Sea launched a project for the evaluation and labelling of the sustainability performance of wine in July 2011. The project aims, amongst others, at issuing guidelines for the sector, building on existing methodologies, such as the OIV and the EU indications (Sustainability in the Italian Viticulture 2014). At present, these sector-specific guidelines are under development and specific matrices for e.g. water and carbon footprinting accounting are recommended for use. Particular emphasis in this project is given to the assessment of the impact on landscape.

3.2.2 Key Issues

The key issues resulting from the analysis for the aforementioned (see Subsection 3.2.1) methodological issues are reported. It must be noted that the results presented are not an exhaustive representation of what can be found in the methodologies, and they are only related to the objectives of this review. These comprise the following aspects: functional unit; system boundary; allocation and by-product, co-product and waste streams; use of resources and impact categories. The following Tables (3.2 and 3.3) include direct citations to the methodological documents examined.

As far as the functional unit selection is concerned (see Table 3.2), most of the methods refer to volume (1 L of wine), which appears to be confirmed also by the selection of weight, as it can be easily transformed into volume by using the density of the product under study.

Table 3.2 Illustration of the analysis results of the methodologies—Functional unit

Methodology	Functional unit
BIER—Beverage Industry Sector Guidance for Greenhouse Gas Emissions Reporting (BIER 2010)	Different for different types of beverages
OIV—Greenhouse Gas Accounting Protocol for the Vine and Wine Sector (OIV 2011)	1 kg of grapes or 0.75 L of wine
JRC—low carbon farming practices (Bochu et al. 2013, p. 19)	"Area or weight"
EPD®—PCR—Wine of fresh grapes, except sparkling wine; grape must (EPD 2013, p. 6)	"1 L of wine including packaging"
EPD®—PCR—Packaged sparkling red, white and rosé wines (EPD 2006, p. 3)	"1 L of wine"

Table 3.3 Analysis results of the methodologies—System boundary

Methodology/reference	System Boundary
BIER 2010, pp. 9–13, 18	*Enterprise inventory approach*
	“ Use the operational control approach as defined by The GHG Protocol to define Scope 1 and 2 emissions Emissions from non-beverage operations such as entertainment, media, or food businesses are not addressed within this Guidance Report GHG emissions from operationally controlled sources as Scope 1 emissions Beverage industry GHG emissions sources included under Scope 2 (indirect emissions) generally fall into one of the following two categories (a) Emissions from directly purchased utilities & (b) Emissions from indirectly purchased utilities Scope 3 emissions include any emissions in the company’s value chain not accounted for under Scopes 1 and 2. The distinction between scopes is unique to each beverage company depending on its operational boundaries. Reporting of Scope 3 emissions is currently voluntary” *Product CF approach*
	“[…] Boundaries are not drawn within the value chain to assign emissions to scopes. Instead, all emissions within the value chain boundary of a specific product are accounted for and parceled to a functional unit, which could be a specific container, serving size, or case of product The areas of the value chain are the same as those described for enterprise reporting, and include the GHG emissions associated with raw material inputs, transportation streams, manufacturing, and disposal/recycling of beverage materials”
OIV 2011, pp. 7–9	*Enterprise Protocol* (*EP*)
	Primary boundaries “All emissions classified as scope 1 (direct GHG emissions) or scope 2 (purchased power utility), are included.” Secondary boundaries “[…] All the activities which are not under the control of the company but on which the company depends for its normal activity are included in the secondary boundaries. Examples of such emissions are: infrastructures, purchased consumables, waste.” “[…] The vitivinicultural companies are only responsible for the emissions that are included into the primary boundaries The emissions classified into the secondary boundaries will be calculated in the case that the companies evaluate the global GHG emissions, related to their activities” *Product Protocol* (*PP*)
	“The boundaries […] are based in the life cycle of the product (business-to-consumer or ‘cradle to grave’):” Grape production

Table 3.3 (continued)

Methodology/reference	System Boundary
	Wine processing Distribution and retail End-life-phase (covering disposal and recycling) "All emissions directly linked with the production process or life cycle of the vitivinicultural product should be included Examples […]: fuel and energy used (even from not owned machinery) in vineyard operations (ex. harvesting, vineyard treatments, etc.); fuel and energy used (even from not owned machinery) in winemaking and processing (ex. bottling…); fuel and energy used in the product transport; input production; waste disposal" "Emissions related to business travels are not included in the PP as they are not directly linked with the wine or grape life cycle Even if inside the wine life cycle boundaries, the consumption phase is not considered in the PP due to its negligible impact"
Bochu et al. 2013, pp. 13–15	"The Carbon Calculator assessment has to be carried out at farm level over a reporting period of one year *Organisational boundaries*
	[It] focuses on the main farming systems of the EU −27 The farm is a physical land area with crops, livestock, buildings, machinery and inputs "Control" approach (100%): the farm is owned by the farmer (financial) or the owner Controls the farmer Data for activities are available (the "farmer" knows them) In most of the cases: inputs purchased are used on the farm The Carbon Calculator is not designed for the following specific farms or on-farm activities Processing and distribution of agricultural products; agritourism, offices, sale of heat; specific agricultural products with specific inputs and emission factors (EF); rice cultivation and other waterlogged farming systems; forest activity (Carbon Calculator is only restricted to trees and hedges along crops or grassland plots); fishery, and the lists of EF are not complete (for lack of specific research), especially for: organic fertilisers for conventional or organic farming if not produced on farm; organic fertilisers for greenhouse nutritive solutions; specific inputs such as plastic pots, plants (vegetables, horticulture…) or seeds; specific machineries or buildings *Environmental footprint boundaries*
	The Carbon Calculator takes direct and indirect activities and associated GHG impacts into account. It uses a "cradle to farm-gate" approach including Direct emissions on the site/farm: emissions for energy used, CH_4 and N_2O (livestock, soils), C storage variations (soil, land use changes, farmland features like trees and hedges) and HFC emissions Indirect emissions (downstream emissions, not on the site) from

Table 3.3 (continued)

Methodology/reference	System Boundary
	Agricultural inputs; end-of-life of plastics and organic matter output as waste; NH_3 volatilisation, leaching and run-off (N_2O) The Carbon Calculator does not include emissions out of farm-gate and up to trailers and consumers: distribution, storage by industries, transportation of farm products, and processing out of the farm"
EPD 2013, pp. 7–8	"*Up-stream processes*
	The upstream processes include the following inflow of raw materials and energywares needed for the production of 1 L of wine of fresh grapes (except sparkling wine) or grape must The production of the grapes in agriculture and at the farm or at the well from the cradle Generation of energy wares used in agriculture, at the farm, and in production Production of other ingredients used in wine of fresh grapes (except sparkling wine) or grape must, detergents for cleaning, etc. Production of primary, secondary and third tier packaging materials Use of fertilisers" *Core processes*
	"The core processes include the production and the packaging of the final wine of fresh grapes (except sparkling wine) or grape must. The core processes include external transport of raw materials and energy wares to final production and internal transportation at the production site" *Downstream processes*
	" Transport from final production to an average distribution platform recycling or handling of packaging materials after use In the EPD, the environmental performance associated with each of the three life-cycle stages above are reported separately"
EPD 2006, p. 4	"*Production phase*
	Field activities (setting up/managing vineyards, irrigation, fertilisation, harvesting crops, transport to pressing facilities) Pressing Vinification (may occur in several phases in different locations) Bottling and packaging (may occur in several phases in different locations)" *Use phase*
	"Distribution of the product (transport to dealers) Use of the product and disposal of packing materials"

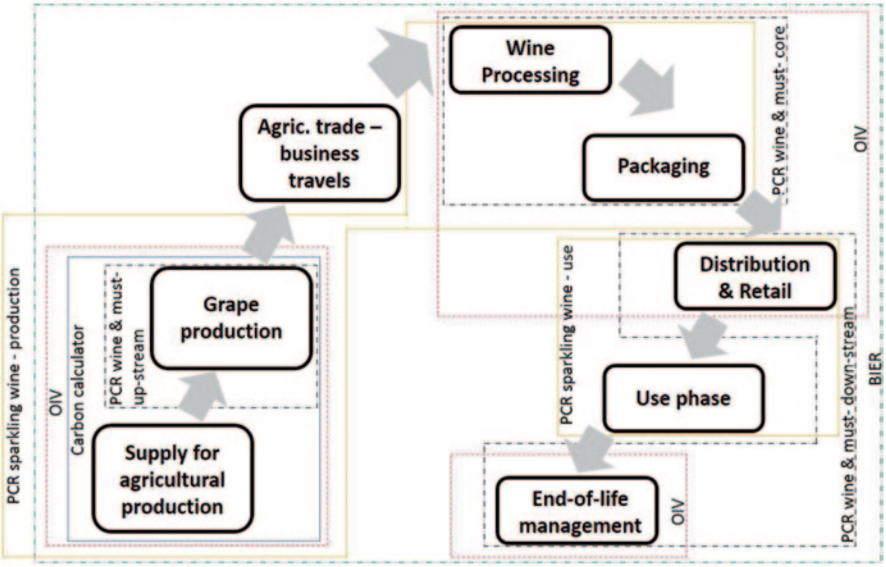


Fig. 3.2 System boundaries—overview of all methodologies examined

As regards the system boundary, this was separately defined for organisation- and product level, where applicable (see Table 3.3). The low carbon farming practices methodology (Bochu et al. 2013) obviously focused on the farm level.

The organisation-related methodologies include the Beverage Industry Guidance (BIER 2010), which uses the same rules for Scope 1, 2 and 3 as the GHG Protocol (see Table 3.3). Similarly, the OIV Guidance distinguishes primary (Scopes 1 and 2) and secondary boundaries (Scope 3), clarifying that vitivinicultural companies are only responsible for the emissions that are included in the primary boundaries (OIV 2011).

Regarding the methodologies at the product level, the PCRs issued by the International EPD System focus on dividing the life cycle phases into upstream, core and downstream ones for non-sparkling wine and grape must and into production and use phase for sparkling wine (see Table 3.3). The Beverage Industry Guidance (BIER 2010) sets the boundaries for the product CF not drawn within the value chain but all emissions within the value chain boundary of a specific product are accounted for and parcelled out to the functional unit. Finally, the OIV Guidance (OIV 2011) includes all life cycle phases, such as grape production, wine processing, distribution and retail, and end-life phase (disposal and recycling), but nevertheless excludes the consumption phase (see Table 3.3) and emissions related to business travel. For an overview of the life cycle stages covered by all the methods characterised in this chapter, please refer to Fig. 3.2.

Table 3.4 illustrates in detail the different approaches adopted by the different methodologies/guidelines with regard to allocation and by-products, co-products and waste streams. In most cases, and where mentioned, allocation is normally

Table 3.4 Illustration of the analysis results of the methodologies—Allocation, by-products, co-products and waste streams

Methodology/reference	Allocation, by-products, co-products and waste streams
BIER 2010, pp. 23–24, 59–60	“The production of certain beverage types may generate **by-product(s)** that can be sold for commercial purposes (such as an animal feed supplement). In this case, a portion of the relevant greenhouse gas (GHG) emissions should be allocated to the by-product itself The GHG emissions associated with the by-product include • An allocation of the relevant GHG emissions from the raw materials • An allocation of the relevant GHG emissions from the transport of the raw materials to the producer • An allocation of the GHG emissions from the production operations (Scope 1 and 2); and • All of the downstream emissions associated with the transportation, storage and sale of the by-product For GHG emissions associated with the *production and transport of the raw materials*, an ***economic value*** model should be used for allocating the relevant GHG emissions between the primary product and the by-product 1. Select the base unit for the raw material (e.g., bushels or tons) 2. Calculate the production yield for both the primary product and by-product (e.g., gallons of product per bushel of raw material) 3. Using the value of the product and by-product, calculate the total revenue per unit of raw material; and 4. Calculate the percentage of revenue contributed by the by-product and use this as the allocation percentage for GHG emissions from raw material production and transportation” “While the GHG emissions of the by-product are not allocated to the life cycle GHG emission of the primary product, beverage producers should calculate the by-product life cycle emissions in order to understand which emissions should be allocated to their products” The **waste** transport “…must be considered at each point up to and including the ultimate disposal location. GHG emissions associated with the incineration or landfilling of wastes are also included in the product carbon footprint The beverage production process also generates a number of **by-products**, which are often beneficially reused, such as bagasse, pumice, spent grains, spilled product, and wastewater Need to account for “waste products” that become **co-products** by virtue of them having a beneficial use (such as composting or feed material) up to the point of product differentiation. […] *Any emissions associated with transporting or further processing of that co-product are allocated to the co-product and not the original product from which it was derived*

Table 3.4 (continued)

Methodology/reference	Allocation, by-products, co-products and waste streams
	Evaluate **wastewater streams** coming from a beverage production facility or other locations in the life cycle to identify the energy demand associated with wastewater treatment. In some cases, wastewater treatment will be performed at a company-controlled facility, and the purchased energy used in wastewater treatment is considered a Scope 2 emission. However, when wastewater is sent off site to a third-party treatment site, such as publicly owned treatment works, include the energy use associated with transportation and treatment in Scope 3 emissions In the case of materials which are **recycled for reuse** in another product’s life cycle (such as PET, which may be used in future PET bottles or for another use), use an **allocation** method ***based on the market recycling rate***. Depending on local market conditions, this approach affords the environmental benefits of recycling either to the recyclers or to the beverage producer” For the case of wine, no co-products are mentioned other than wine/grape
OIV 2011, pp. 25–26	*Waste disposal*
	“GHG emissions from **aerobic waste treatment, both solid and liquid**, (arising from the biogenic carbon fraction of the waste) are considered part of the *short term carbon cycle and are excluded from the PP* [*and EP*]. The emissions arising from the vine biogenic carbon fraction are included as part of the vine carbon cycle.” **Energy consumed in the disposal** is *included* in the PP (and for the EP, if outside the company boundaries), is included in the secondary boundaries *Direct reuse*:
	Emissions related to the **reuse of wine byproducts or waste** are *included in the EP* if inside the boundaries of the company are *excluded from the PP* and should be integrated in the life cycle of the new product in which they are integrated as an input “In the vine and wine industry, examples of reuse included in the PP and EP (when inside the company boundaries) are: pruned canes ground for soil amendment; preparation and burning of wood residues or grape marc for energy purposes; compost preparation; distillation of wine or grape marc.” *Recycling*
	Emissions related to the **recycling of wine by-products or waste** are *included in the PP and in the primary boundaries of the EP*, when the company is responsible for the recycling process

Table 3.4 (continued)

Methodology/reference	Allocation, by-products, co-products and waste streams
	PP: "A special case in the vine and wine industry is the recycling of the glass bottles: In order to avoid double accounting, and taking into account that glass from bottles can be recycled infini, the recycling GHG emissions *are already included in the glass production emissions figures*. Note: if this rule is not applied, the cullet production emissions would be assigned *twice*: first as glass recycling (of the previous bottle) and second as raw material use for the production of the successive bottle" EP: "If the company is responsible of the recycling of glass bottles, the recycling emissions should be carefully studied due to its importance when applying the EP. Taking into account that glass from bottles can be recycled infini, and in order to simplify the calculation, the recycling GHG emissions used could be the upstream ones (recycling figures of the bottle before the company use it)"
Bochu et al. 2013, pp. 19, 106	*Multiple outputs*
	"The Carbon Calculator systematically uses the **protein or energy allocation** key to distribute GHG emissions between: Milk and meat from dairy animals (cow, sheep, goat); Eggs and poultry meat for laying hens As processing is outside the boundaries of the Carbon Calculator, there is *no possibility to allocate GHG emissions between co-products resulting from processing*." "Distribution of GHG emissions **between products and co-products** throughout the supply chain are determined according to the three main rules: Type 1: direct assignment during the data input. For example, the GHG emissions (manufacturing) of mineral fertilisers applied on a crop will be directly attributed to this product (depending on the end-use of the crop) Type 2: automatic allocation. For example, on a specialised dairy farm (products = milk and meat from dairy animals) an automatic allocation rules 85–15% base on protein content for enteric fermentation will be implemented Type 3: assignment made by the user himself. For example, in case of propane gas used on a farm, the user will distribute the percentage/quantity of use of this input between different available products" The user cannot select these co-products, as they are automatically created For the case of wine, no co-products are mentioned other than wine/grape
EPD 2013, pp. 9, 11	"Allocation between different products and co-products **shall be based on product mass**." "The potential environmental impacts and benefits of **recycling** of primary packaging shall be illustrated in the EPD

Table 3.4 (continued)

Methodology/reference	Allocation, by-products, co-products and waste streams
	Impacts could be calculated taking into account a typical scenario of the area in which wine is mainly distributed" For the case of wine, no co-products are mentioned other than wine/grape
EPD 2006, p. 6	"For each type of product belonging to the product category (packaged sparkling red, white and rosé wines) it is necessary to prepare specific Environmental Declarations. In case two types of product happen to be produced at the same site, the data regarding the specific production activity must be *allocated proportionately according to the following formula*: (**Total production of the type of product/total output of the site**) * **100 = Percentage of allocation** In vinification phase the word 'production' means: amount of product obtained from grapes pressing plus addition of musts or wines coming from other plants if any, plus starting goods on hand minus final goods on hand" Here, dregs and pomace are mentioned as by-products

performed by mass. Protein or energy allocation is also mentioned in the low carbon farming practices methodology (Bochu et al. 2013).

As far as the use of resources and the selection of impact categories are concerned, please refer to Table 3.5. For GHG-related methodologies, the impact category taken into consideration is obviously global warming. The two PCRs, nonetheless, apart from the greenhouse effect, cover a broader range of environmental impact categories such as acidification, stratospheric ozone depletion, formation of oxidising photochemicals, eutrophication, etc. In addition, these PCRs tackle a series of resources, such as renewable and non-renewable resources, water use, electricity consumption, etc.

3.2.3 Simplified LCA Tools

The widespread use of LCA amongst public and private economic sectors has rendered it a powerful tool for the assessment of the environmental performance of products. For example, the application of LCA has become necessary for many firms, in particular Small and Medium-sized Enterprises (SMEs), which in most cases are related to wine production facilities (Arzoumanidis et al. 2013c). These firms often have to cope with lack of time, knowledge and resources, thus finding a full LCA application a difficult task (Arzoumanidis et al. 2014a). Therefore, simplification in LCA may often occur within the phase of LCI, LCIA or both (Arzoumanidis et al. 2013c), limiting the inclusion of processes or environmental impact categories to be considered.

Table 3.5 Analysis results of the methodologies—use of resources and impact categories

Methodology/reference	Use of resources and impact categories
BIER 2010	Greenhouse effect (GWP) in t CO_2 equiv
OIV 2011	Greenhouse effect (GWP)
Bochu et al. 2013	Greenhouse effect (GWP) in t CO_2 equiv
EPD 2013, pp. 11–12	“*Use of resources*
	The consumption of natural resources and resources shall be reported in the EPD Input parameters, extracted resources Non-renewable resources/Renewable resources Material resources Energy resources (used for energy conversion purposes) Water use Electricity consumption (electricity consumption during manufacturing and use of goods, or during service provision)” *Potential environmental impacts*
	“Emissions of greenhouse gases (expressed in global warming potential, GWP, in 100-year perspective) Emission of ozone-depleting gases (expressed as the sum of ozone-depleting potential in CFC 11-equivalents, 20 years) Emission of acidification gases (expressed as the sum of acidification potential expresses in SO_2-Eq.) Emissions of gases that contribute to the creation of ground level ozone (expressed as the sum of ozone-creating potential, ethene-equivalents) Emission of substances to water contributing to oxygen depletion (expressed as PO_4-Eq.) *Other indicators*
	“The following indicators shall be reported in the EPD Material subject for recycling Hazardous waste, kg (as defined by regional directives) Other waste, kg Toxic emissions Land use, m^2a for land occupation”
EPD 2006, pp. 7–8	“Use of renewable resources Without energy content With energy content Use of non-renewable resources Without energy content With energy content Consumption of electrical energy Categories of emissions Gas with greenhouse effect (GWP) kg CO2 equiv. (100 years) Acidification (AP) kmol H +

Table 3.5 (continued)

Methodology/reference	Use of resources and impact categories
	Reduction of stratospheric ozone (ODP) kg CFC-11 equiv. (20 years)
	Formation of oxidising photochemicals (POCP) kg ethane equiv
	Eutrophication (NP) kg O_2
	The above categories comply with enclosure A of MSR 1999:2
	Wastes
	Hazardous wastes, kg
	Non-hazardous wastes, kg”

The application of simplified LCA tools may require, in general, limited time and resources (Arzoumanidis et al. 2013c). Simplified tools appear to have clear and easy to understand calculation and visualisation methods and can be considered as suitable for an effective communication of the environmental performance of products and services (Arzoumanidis et al. 2013c). Simplified LCA tools normally offer characteristics such as user friendliness along with the life cycle thinking orientation, as well. Several opportunities were identified that could render such tools more easily adoptable: a proactive approach as regards the strategic management of the environmental variable, sensitivity of management to environmental issues and an interest in eco-labelling initiatives on the side of the market (Salomone et al. 2012).

In contrast, simplified LCA tools are characterised by their difficulty in incorporating the methodological differences across firms and sectors. Furthermore, several weaknesses can be identified for such tools. For example, reduced scope and increased subjectivity can be considered as weaknesses of simplified LCA tools (Arzoumanidis et al. 2013c). In addition, external threats are mostly connected to a general lack of environmental awareness by the firms combined with a central focus on short-term problems, mainly due to market pressure (Arzoumanidis et al. 2013c). Besides that, the fact that environmental management tools are not normally perceived as an opportunity for SMEs has also to be taken into consideration (Masoni et al. 2001). Technical staff’s lack of willingness and/or time were two other critical issues identified. Finally, it must be noted that environmental issues are often perceived as limitations and a source of additional and often unknown (or hidden) costs (Masoni et al. 2004).

When choosing the most suitable simplified LCA tool, the objectives of a study, and more importantly the characteristics of the product under study, are issues to be considered (Arzoumanidis et al. 2014a). The modelling of one tool can be for instance more suitable for creating a phase of the life cycle. Finally, the degree to which the incorporated database can contain most of the processes that are needed for the study can play a quite important role in the selection of the most suitable tool (Arzoumanidis et al. 2014a). As regards wine, for instance, the existence of specific processes related to the agricultural and/or vinification phase may play an important role in the selection or not of a certain tool.

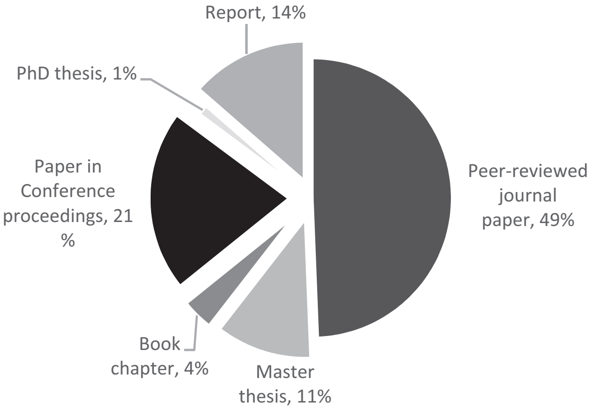


Fig. 3.3 Studies identified in the review of the LCA of the wine sector, published from 2001 to 2013 (last update on 31 July 2013)

3.3 Critical Analysis of Life Cycle Assessment: Case Studies in the Wine Sector

This chapter reports the results of a comprehensive critical analysis in the domain of the LCA of wine. An extensive search was conducted to select studies from the international literature that could encompass all the issues related to the LCA of wine. Following a screening process, 81 papers published between 2001 and 2013 (last update at July 2013) were finally selected and analysed, including papers available in peer-reviewed journals and conference proceedings, official reports, such as analyses commissioned by private or public institutions, and thesis reports (grey-literature). Figure 3.3 shows the percentage breakdown of the 81 investigated studies according to the typology.

The complete list of the reviewed studies, including the summary of findings on wine Environmental Life Cycle Approaches, is available in Table 3.7.

In order to outline the main peculiarities of an LCA study in the wine sector, examine which improvements could be made and suggest a number of lessons learnt, nine aspects were identified and analysed: (1) *Goals* (Sect. 3.3.1); (2) *Functional Unit* (FU) (Sect. 3.3.2); (3) *System boundary* (Sect. 3.3.3); (4) *Data issues* (Sect. 3.3.4); (5) *Handling multi-functional processes* (Sect. 3.3.5); (6) *Life Cycle Impact Assessment* (*LCIA*): *impact categories, assessment methods and indicators* (Sect. 3.3.6); (7) *Interpretation* (Sect. 3.3.7); (8) *Critical analysis* (Sect. 3.3.8); (9) *Comparative analysis* (Sect. 3.3.9).

The investigation performed on the first five aspects applied a mere conceptual approach (no quantitative results were generated for those issues discussed from Sect. 3.3.1 to 3.3.5). In contrast, the analysis carried out from Sect. 3.3.6 to 3.3.9 had a more quantitative nature.

It should be noted that for the critical analysis related to the aspects dealt with in Sect. 3.3.1–3.3.5, only 59 papers were considered among those included in Table 3.7. The excluded papers comprise papers regarding only one or few subsystems of the wine value chain, such as: packaging (Bengoa et al. 2009; Cleary 2013;

González-García 2011a, b; Latunussa 2011; Patingre et al. 2010; Woodward 2010); packaging and transportation (Cholette and Venkat 2009; WRAP 2007); closure systems (Gabarell et al. n.d.; Kounina et al. 2012; Rives et al. 2011, 2012, 2013); fertilisers (Ruggieri et al. 2009); waste management (Dillon 2011).

3.3.1 Goals

In almost all cases, the studies had the general aim of assessing the environmental impacts of wine. After the various papers related to wine were analysed, it was evident that the objective of the study in most cases was to estimate the environmental impacts in order to identify the hot spots in the life cycle of wine and to assess the effect of potential improvement options/possibilities.

Many studies dealt with comparative assessments; for instance, comparisons concerned white and red wines (Notarnicola et al. 2003), high quality and average quality wines (Notarnicola et al. 2003), wines from different regions (Vàzquez-Rowe et al. 2013).

A few studies compared different farming strategies: conventional and organic (Barberini et al. 2004; Cecchini et al. 2005b; Kavargiris et al. 2009; Niccolucci et al. 2008); industrial, organic and biodynamic (Eveleth 2013); organic and semi-industrial (Pizzigallo et al. 2008); biodynamic, conventional and an intermediate biodynamic conventional wine-growing plantation (Villanueva et al. 2013). However, for example, the goal of Notarnicola et al. (2003) was not a direct comparison of different wines, such as red and white wine or high quality and medium quality wine, as these are not "perfect substitutes", but different types of wines. Therefore, the differences in each of the environmental profiles wine had to be examined.

Other comparisons were made between different wineries to assess performances. For example, in Pattara et al. (2012a), one of the goals of the study was to assess which of two wineries had the highest performance when it came to CO_2-eq emissions associated with the production of Montepulciano d'Abruzzo DOC.

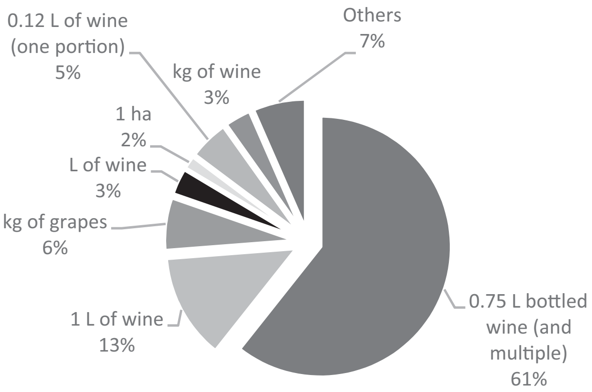
Moreover, the suitability of simplified LCA tools, such as VerdEE (Morgante et al. 2004; Petti et al. 2006), for the evaluation of the environmental performance of wine was also assessed, supporting the use of simplified tools as previously highlighted in Sect. 3.2.4.

Environmental assessments were also made by calculating the Carbon Footprint (BIER 2012; Bosco et al. 2013; Fearne et al. 2009; Pattara et al. 2012b; Vázquez-Rowe et al. 2013) and the Water Footprint (e.g. Ene et al. 2013; Pina et al. 2011) of wine, or by comparing the Ecological Footprint of different wines (e.g. Niccolucci et al. 2008).

On the other hand, Colman and Päster (2009) did not explicitly use the Carbon Footprint method, but developed a similar model for quantifying greenhouse gas emissions from the production and distribution of a bottle of wine to determine the phase with the greatest impact in terms of global warming.

Another goal, detected in Cecchini et al. 2005a, was the evaluation, through the application of different characterisation methods such as Eco-indicator 99,

Fig. 3.4 Percentage breakdown of the analysed studies according to the different Functional Units used



EPS2000 and EDIP96 applied with SimaPro 5.0® software for the LCIA phase, of the impacts on the environment and on human health caused by the processes involved in wine bottle production.

3.3.2 Functional Unit

Amongst the 61 studies analysed, the Functional Unit (FU) was typically determined in terms of product mass or cultivated area units. In particular, as pointed out also in previous reviews (Benedetto 2013; Petti et al. 2010b; Rugani et al. 2013), 61 % of the studies (Fig. 3.4) define the FU as a 750 ml bottle of wine (or multiples thereof). Most of the authors consider this amount of wine as an FU because that is the most usual way of delivering the finished product to the market.

On the other hand, other authors (e.g. Arcese et al. 2012) considered 1 L of wine as an FU (13 % of the studies analysed), due to the fact that they aimed to avoid accounting for possible differences in packaging strategies within the same company, and thus to focus only on the quantity of the final product purchased by the customer (see also Fig. 3.7).

However, many authors, who generally focused on the agricultural phase referred to other FUs, such as 100 L of wine (Pattara et al. 2012a), kg of grapes (6 % of the studies took various amounts of grapes expressed in kg as an FU) or kg of wine (used in 3 % of the analysed cases).

Three case studies (5 % of the total) considered 0.12 L of wine (one portion) as an FU. This unusual choice probably reflects one restaurant serving corresponding to 1.3 standard portion (12 g of pure alcohol × 1.3 = 15.6 g). This corresponds to 12 cl of wine with an alcohol content of 13 % (Mattila et al. 2012b).

In Mann et al. (2010) the FU used was the amount of impact due to the 2009 Cru vineyard's production; in Niccolucci et al. 2008 two types of FUs are defined: a unit mass for the bottle and a unit area for vineyards; while in Notarnicola et al. (2007, 2008) the FU is related to enrichment of must by one alcoholic degree. These cases are categorised as "Others" for the particular nature of the FU.

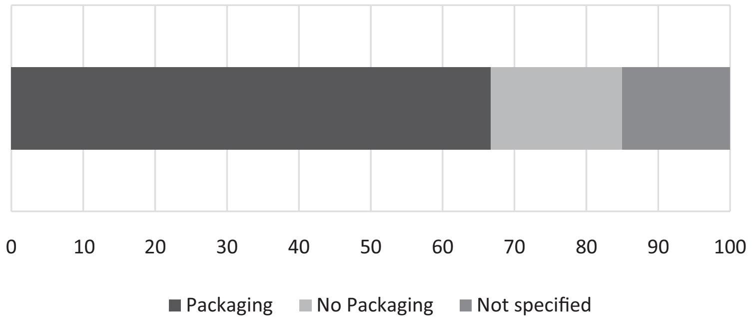
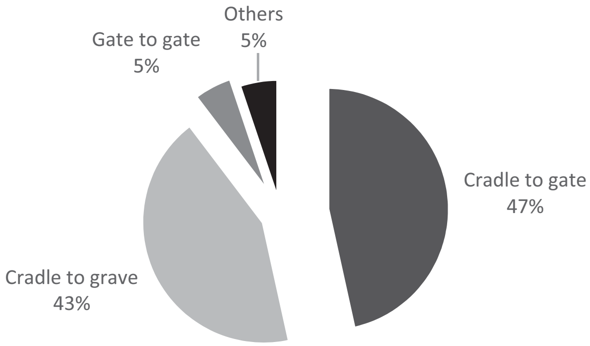


Fig. 3.5 Percentage breakdown of the analysed studies according to the packaging inclusion in FU

Fig. 3.6 Percentage breakdown of the analysed papers according to the System Boundary considered



Only one study (Kavargiris et al. 2009) used 1 ha as an FU to compare organic and conventional vineyards.

Sixty seven percent of the studies analysed considered some form of packaging in the FU. Figure 3.5 shows that packaging was not considered in 18 % of cases, and 15 % of the studies did not explicitly indicate whether the packaging was included or not in the FU.

3.3.3 System Boundary

According to ISO 14044 (ISO 2006, p. 8): “The system boundary determines which unit processes shall be included within the LCA”. As pointed out by Rugani et al. (2013), the variability of impacts across different case studies of wine may be strongly influenced by the system boundary identification. As a likely consequence, the choice of the relevant and irrelevant processes to be included or not in the system boundary could represent a problem in the definition of environmental performance of wine (Notarnicola et al. 2003).

Forty three percent of the studies (Fig. 3.6) claimed to consider the complete life cycle from “cradle to grave”, including the extraction and the processing of raw materials, production, transport and distribution, use, reuse and maintenance, recycling of the components and final disposal. However, not all of them defined the same life cycle phases.

Most of the LCA studies analysed did not consider the vineyard-planting subphase (Ardente et al. 2006; Gazulla et al. 2010; Neto et al. 2013; Notarnicola et al. 2003). A few studies, however (see for example, Benedetto 2013; Bosco et al. 2011), included it because of its agronomic importance and potential impact on GHG emissions.

Furthermore, the consumption phase was not considered in most of the papers because of the lack of relevant data or the negligible environmental impacts of this phase, e.g. transport from the point of sale to the place of consumption or refrigeration, if any (Gazulla et al. 2010; Neto et al. 2013).

Forty seven percent of the analysed papers assessed the life cycle of wine from “cradle-to-gate”, which included the impacts deriving from the phases of grape cultivation, wine production and storage, bottling and packaging activities. Within this percentage of studies, some authors referred to the LCA system boundary from the extraction of raw materials to the distribution phase, with a “cradle-to-market” perspective. The latter differs from the classical “cradle-to-gate” perspective in that it also includes the phase of wine distribution (Arzoumanidis et al. 2013b).

Most of the studies did not include phases such as wastewater treatments or production and emissions of herbicides and pesticides because of the lack of relevant data and/or importance (Gazulla et al. 2010); another reason could be the difficulty of modelling the dispersion of pesticides and nutrients in the environment (Notarnicola et al. 2003).

A few authors (5 %) focused their study on a single life cycle stage, with the aim to address specific research or policy questions. This is the case, for example, with the wine enrichment phase (Notarnicola et al. 2007) and the agricultural phase (Villanueva et al. 2013).

Lastly, other studies (5 %) considered a system boundary “from gate-to-gate”, they focused their attention on specific phases. For example, Reich-Weiser et al. (2010) considered only scenarios of transport to New York after wine had been packaged for sale in Napa, California, and Bordeaux.

3.3.4 Data Issues

The LCA studies on wine highlighted the importance of obtaining significant onsite data for the processes included in the system (as reported in Petti et al. 2010b).

In practice, a great number of brands in Europe base their grape production phase on a broad number of vine-growers who sell their grapes to the wineries every year. This situation renders environmental evaluations on viticulture complicated, since multiple data for multiple facilities have to be handled. The use of average values for this type of multiple dataset usually entails large standard deviations that may impede adequate interpretation of the results (Reap et al. 2008; Rugani et al. 2013; Weidema and Wesnæs 1996). In other words, the use of average inventory data for analysing a multiple set of vine-growing plantations is likely to be subject to significant data variability, distorting the individual performance of each of the assessed vineyards (Vázquez-Rowe et al. 2012a).

In the studies analysed many of the data collected for the processes of grape-growing, winemaking and bottling are from primary sources. These sources include data collected (often by means of questionnaires) from vineyard and winery staff and power company sources (e.g. Benedetto 2013; Bosco et al. 2013; Gazulla et al. 2010; Herath et al. 2013a; Kavargiris et al. 2009).

Data are often derived from secondary sources, as in the studies on the distribution phase of the final product to the consumer (e.g. Barry 2011), for the fuel and electricity supply chain, the manufacturing and transport of agrichemicals, winemaking additives and glass bottles (LCI databases such as BUWAL®, ecoinvent®, SimaPro®, GaBi professional®, IDEMAT®, amongst amongst others).

3.3.5 Handling Multi-functional Processes

In the specific case of wine, by-products such as grape residues and fermentation sediments are obviously impossible to produce separately; therefore, it would make no sense to divide the winemaking process into two or more independent sub-processes.

Most of the studies did not refer to the allocation of by-products and co-products. Others did not consider the allocation process because marc and lees obtained from the vinification process were excluded from analysis (and in one case they were returned to the soil; Rallo 2011) or because some allocation procedures were automatically included within the LCA software calculations (Arcese et al. 2012).

Vázquez-Rowe et al. (2012b) did not perform any allocation because, although wine was not the only product derived from winery transformation, grapes were the only product acquired from the cultivation phase, since all by-products were obtained once the grapes were delivered at the winery. Conversely, a series of residues were generated during the wine production stage. These products were incorporated into the vineyard as fertiliser. Therefore, no allocation was considered in this stage since the only marketable product was wine.

The problem of how to allocate the different co-products of winemaking (skins, pips and stalks, etc.) is tackled in the literature by allocation of the environmental burden by mass (Bosco et al. 2011), economic value (Cecchini et al. 2005a, b) or a combination of both (Nicoletti et al. 2001).

As regards allocation by mass, the co-products leaving the systems, such as stalks, lees and marc, were considered as solid waste for which there was no disposal treatment, since they became raw materials for other productions, respectively compost for stalks and tartaric acid for marc (Notarnicola et al. 2003).

Arguably, Gazulla et al. (2010) chose economic allocation because it reflected the actual thrust behind the entire wine industry in a better way than mass- or energy-based allocations could do; since the main product was obviously wine itself, and not any of its by-products.

3.3.6 Life Cycle Impact Assessment (LCIA): Impact Categories, Assessment Methods and Indicators

The general aim of Sect. 3.3.6 was to analyse and discuss how and to what extent LCIA is applied to the wine sector in a wide range of the reviewed literature. To this end, six key issues were selected as intrinsically related to the LCIA sphere, and then analysed along with the 81 studies considered in Table 3.7. These six key issues were: (1) LCIA method(s); (2) LCIA phase(s); (3) LCIA results; (4) LCIA result quality; (5) Interpretation phase; (6) Indicator(s)/method(s) other than LCIA. As illustrated in Table 3.6, each key issue was assigned a score from one to three. This operation was performed to compare every aspect of the LCIA sphere across all the selected studies, normalising any qualitative (e.g. quality of results, interpretation profiles, etc.) or quantitative (e.g. number of impact categories considered, LCIA results, etc.) information on a common semi-quantitative metric. The rationale behind the '1–3' scoring range in Table 3.6 was the same for all six issues and reflected the breadth and depth of information provided by each analysed study with regard to the key issue considered. For example, concerning key issue 1, score 1 was attributed to the studies that did not apply any LCIA method, score 2 to the studies that included only one single-score method (e.g. carbon footprint), and score 3 to the studies that carried out an LCIA with a multi-score perspective (e.g. application of two or more LCIA indicators). A complete description of the properties and assumptions behind this scoring approach is reported in Table 3.6. The key issues numbered 1–4 are discussed in Sect. 3.3.6, key issue 5 is discussed in Sect. 3.3.7 and key issue 6 in Sect. 3.3.9 (Table 3.6).

Table 3.6 shows the main topics investigated in this section: the type of LCIA method adopted and the phases reached in the analysis, the number and type of the indicators used to outline a general profile of the impact assessment associated with wine production and the quality of the impact results obtained.

The results of the review, carried out following the methodology described above, are synthetically presented in Fig. 3.7.

From the review of the 81 papers on the LCA method adopted (see key issue 1 in Table 3.6), it emerged that 20 % of the papers did not carry out the LCIA phase. In many cases, the study provided an overview of key drivers for wineries to move towards sustainability practices and outlined actual environmental practices: e.g. Dodds et al. (2013) for the New Zealand wine industry and Ardente et al. (2006), who presented a preliminary analysis of an environmental management scheme (EMS) and environmental product labelling potential in the winery sector (POEMS) with a Sicilian wine production case study. The reason why LCIA is not explicitly included in the scope of the LCA-based study may be because of the need to consider criticalities and environmental aspects that are not usually dealt with by typical LCIA approaches. For example, some papers focussed on a detailed inventory (Pizzigallo et al. 2008; Reich-Weiser et al. 2010; Notarnicola et al. 2007) or presented a comparison of published studies on the LCA of wine on the basis of their methodologies and results, as in Woodward (2010), with regard to packaging

Table 3.6 Key issues analysed in the present LCIA review (Sects. 3.3.6–3.3.9) with a description of the score properties

Key issue	Score range	Scoring description
1. LCIA method(s)	1–3 From 1 to 3 according to the increase of breadth and depth of information provided	1: *LCIA method (s) not applied* 2: *Single-score method* (only one impact issue evaluated) 3: *Multi-score method* (more than one impact criteria evaluated)
2. LCIA phase(s)		1: *LCIA not performed* or *inventory results used otherwise* 2: *Only characterisation is performed* 3: *Characterisation+ normalisation+ weighting*
3. LCIA results		1: *Lower granularity* = only qualitative analysis or quantitative but with scarce resolution (low detail of information or only relative contribution results) 2: *Medium granularity* = quantitative results with good resolution (absolute values provided by process phases) 3: *Higher granularity* = quantitative results with wider resolution and transparency (absolute values by detailed/site-specific inventory process)
4. LCIA result quality		1: *Lower quality* = incomplete system boundary + not sufficiently representative LCI data + uncertainty neither considered nor evaluated 2: *Medium quality* = more complete system boundary + sufficiently representative LCI data + uncertainty or variability considered but not necessarily evaluated 3: *Higher quality* = almost complete system boundary + sufficiently representative LCI data + uncertainty and/or variability evaluated
5. Interpretation phase		1: Reporting of this basic information *Identification of the significant issues based on the LCI and/or LCIA results* 2: Reporting of this additional information *Conclusions, limitations, and recommendations* 3: Reporting of further evaluations about *Completeness, sensitivity and consistency checks*

Table 3.6 (continued)

Key issue	Score range	Scoring description
		Appropriateness of the definitions of the system functions, the functional unit and system boundary and/or identification of the limitations identified due to data quality assessment and sensitivity analysis
6. Indicator(s)/ method(s) other than LCIA		1: *Conventional LCA* = only LCIA method(s) applied 2: *Only use environmental assessment metric(s) other than those typically included in LCIA methods applied* 3: *Comparative/combination purpose* = application of LCIA + other (complementary) environmental assessment metric(s)

options. Finally, other studies concerned the application of GHG emissions' inventory to the wine supply chain (Arzoumanidis et al. 2013b; Kavargiris et al. 2009; WRAP 2007). Interestingly, Kavargiris et al. (2009) performed a comparison between conventional and organic white wines in Greece based on energy balance and carbon-related emissions, and Reich-Weiser et al. (2010) analysed the GHGs impact analysis of shipping and distribution systems. On the same subject, Arzoumanidis et al. (2014b) explored biogenic accounting emissions in the case of wine, which is not yet included and defined in the international standards (BSI 2011; ISO 2013). However, when authors do not include LCIA, they tend to address aspects typically outwith the environmental sphere, as shown by the preliminary evaluation on social LCA in the wine sector performed by Sanchez Ramirez (2011), who identified 26 indicators according to the UNEP/SETAC LCI framework (UNEP/SETAC 2009). Soosay et al. (2012) investigated the worth of sustainable value chain analysis (SVCA) as a tool for promoting better alignment between the allocation of resources in the supply chain industry and consumer preferences in a specific target market.

Twenty-eight per cent of the selected studies performed the LCIA but from a single-score perspective, thus addressing only one aspect of the cause-effect chain (EC 2010). More specifically, the majority of those studies (18 out of 23) analysed the global warming potential (typically referred to as “Carbon Footprint–CF”), whereas the water footprint (WF) was considered in just three cases (Ene et al. 2013; Herath et al. 2013a, b) and land use in just one case (Mattila et al. 2012b). Moreover, many international organisations for wine production, such as the International Wine Carbon Calculator (IWCC) and the OIV, are working to standardise the CF estimation protocols and guidelines currently under development (Pittock et al. 2003; Hayes and Battaglene 2006; Webb et al. 2007; see also Sect. 3.2.1). This is because their focus is explicitly on the continuous improvement of the wine life cycle and new technology options might also offer opportunities to mitigate impacts

Table 3.7 Summary of findings on wine environmental life cycle approaches

Author	Year	Type of publication	Wine geographic location	Type of wine	Functional Unit (FU)	System boundaries[a]
Amienyo	2012	PhD thesis	UK	Red wine	1000 L of beverage, 0.75 L red wine glass bottle	C-G
Aranda et al.	2005	Peer-reviewed journal	Spain	n.s.	0.75 L bottled wine	C-G
Arcese et al.	2012	Peer-reviewed journal	Italy	n.s.	1 L of wine	C-R
Ardente et al.	2006	Peer-reviewed journal	Italy	Red wine	0.75 L bottled wine	C-R
Arzoumanidis et al.	2013b	Book chapter	Italy	Red wine	0.75 L bottled wine	C-M
Barberini et al.	2004	Master thesis	Italy	Red wine	0.75 L bottled wine	C-G
Barry	2011	Master thesis	New Zealand	White wine	0.75 L bottled wine	C-G
Benedetto	2013	Peer-reviewed journal	Italy	White wine	0.75 L wine	C-W
Bengoa et al.	2009	Conference proceedings	Canada	n.s.	To hermetically hold 0.75 L of table wine for two years	C-G
BIER	2012	Report	Europe and North America	n.s.	0.75 L glass bottle, six-pack	C-Co
Bosco et al.	2011	Peer-reviewed journal	Italy	Red wine	0.75 L bottled wine	C-G
Bosco et al.	2013	Peer-reviewed journal	Italy	Red wine	0.75 L bottle of wine	C-G
Burja and Burja	2012	Peer-reviewed journal	Romania	White wine	1 kg of grape	n.s.
Camilleri	2009	Conference proceedings	n.a.	n.s.	n.a.	n.a.
Carballo Penela et al.	2009	Peer-reviewed journal	Spain	White wine	0.75 L bottled wine	C-G
Carta	2009	Master thesis	Italy	Red wine, mixed red/white	0.75 L bottled wine	C-G
Catania and La Mantia	2006	Conference proceedings	Italy	n.s.	0.75 L bottled wine	C-G
Cecchini et al.	2005a	Master thesis	Italy	Red wine	0.75 L bottled wine	C-G
Cecchini et al.	2005b	Master thesis	Italy	Red wine	0.75 L bottled wine	C-R

Table 3.7 (continued)

Author	Year	Type of publication	Wine geographic location	Type of wine	Functional Unit (FU)	System boundaries[a]
Cecchini et al.	2006	Master thesis	Cile	Red wine	0.75 L bottled wine	C-R
Cholette and Venkat	2009	Peer-reviewed journal	USA	n.s.	6-bottles box transported	W-R
CIV	2008	Report	Italy	Sparkling red wine	1 L bottled wine	C-G
Cleary	2013	Peer-reviewed journal	n.s.	n.s.	The packaging required for 1 L of young, non-sparkling wine and that for 750 ml of spirits	C-G
Colman and Päster	2009	peer-reviewed journal	Australia, France	Red and white	0.75 L bottled wine	C-G
Comandaru et al.	2012	Peer-reviewed journal	Romania	White wine	0.75 L bottled wine	C-G
Del Principe	2013	Report	n.s.	n.s.	1 L of wine including packaging	C-G
Dillon	2011	Master thesis	South Africa	n.s.	1000 L of wine	n.a.
Ene et al.	2013	Peer-reviewed journal	Romania	n.s.	0.75 L bottled wine	C-G
Eveleth	2013	Report	n.s.	n.s.	1 L of wine	C-R
Fearne et al.	2009	Conference proceedings	Australia	n.s.	n.s.	C-G
Gabarell et al.	n.d.	Conference proceedings	n.s.	n.s.	One million of natural cork stoppers	P-G
Gazulla et al.	2010	Peer-reviewed journal	Spain	Red wine	0.75 L bottled wine	C-G
Gonzalez et al.	2006	Report	France, Sweden	Red wine	1 L of wine	C-G
Gonzalez-Garcia	2011a	Peer-reviewed journal	n.s.	n.s.	1 kg of wood based products (among which wine boxes)	n.a.
Gonzalez-Garcia	2011b	Peer-reviewed journal	n.s.	n.s.	One wood box (1.35 kg) for the storage of three standard wine bottles	P-R

Table 3.7 (continued)

Author	Year	Type of publication	Wine geographic location	Type of wine	Functional Unit (FU)	System boundaries[a]
Greendelta	2011	Software guideline report	France	n.s.	1 kg of rapes	n.a.
Greenhaigh et al.	2011	Report	New Zealand	White wine	0.75 L bottled wine	C-G
Herath et al.	2013a	Peer-reviewed journal	New Zealand	Super-premium wines	0.75 L bottled wine	C-W
Herath et al.	2013b	Peer-reviewed journal	New Zealand	Super-premium wines	0.75 L bottled wine	C-W
Jimenez et al.	2013	Peer-reviewed journal	Spain	Red wine	1000 kg grape	C-G
Kavargiris et al.	2009	Peer-reviewed journal	Greece	White wine	1 ha	C-W
Kounina et al.	2012	Peer-reviewed journal	n.s.	n.s. (average from literature)	0.75 L bottled wine	C-G
Leonardi et al.	2006	Report	Italy	Red, white and rosè wines	1 L of wine	C-G
Latunussa	2011	Master thesis	n.s.	n.s.	Packaging and distribution of 1000 L of wine	C-G
Mann et al.	2010	Conference proceedings	USA	Aperitif wine	Total amount of bottles of Cru production for the year 2009	C-W
Mattila et al.	2011	Peer-reviewed journal	Spain	Red wine	One portion of wine equal to 0.12 L	C-Co
Mattila et al.	2012a	Peer-reviewed journal	Spain	Red wine	One portion of wine equal to 0.12 L	C-R
Mattila et al.	2012b	Peer-reviewed journal	Spain	Red wine	One portion of wine equal to 0.12 L	C-R
Morgante et al.	2004	Conference proceedings	Abruzzo region	Red wine	6 bottles of 0.75 L with primary and secondary packaging	C-G
Neto et al.	2013	Peer-reviewed journal	Portugal	White wine	0.75 L bottled wine	C-W
Niccolucci et al.	2008	Peer-reviewed journal	Italy	Red wine	Unit mass of bottle & unit area of vineyard	C-R

Table 3.7 (continued)

Author	Year	Type of publication	Wine geographic location	Type of wine	Functional Unit (FU)	System boundaries[a]
Nicoletti et al.	2001	Conference proceedings	Italy	Red wine	1 L of wine (not bottled)	C-W
Notarnicola et al.	2003	Chapter in edited volume	Italy	Red wine and white wine	0.75 L bottled wine	C-W
Notarnicola et al.	2007	Chapter in edited volume	Italy	n.s.	The enrichment of 1000 L of must by 1 alcoholic degree	V
Notarnicola et al.	2008	Conference proceedings	Italy	n.s.	1000 L of must for which the aimed enrichment is 1 alcoholometric degree from 10° to 11°	C-G
Notarnicola et al.	2010	Conference proceedings	Italy	red wine	133 bottles of 0.75 L	C-R
Patingre et al.	2010	Report	Different countries	n.s.	Packaging and distribution of 1000 L of wine	P-G
Pattara et al.	2012a	Conference proceedings	Italy	Red wine	100 L red wine without packaging	C-W
Pattara et al.	2012b	Peer-reviewed journal	Italy	Red wine	0.75 L bottled wine	C-G
Petti et al.	2006	Conference proceedings	Italy	red wine	0.75 L bottled wine	C-R
Pina et al.	2011	Poster	Portugal	White wine	0.75 L bottled wine	C-B
Pizzigallo et al.	2008	peer-reviewed journal	Italy	red wine	1000 kg of wine	C-G
Point et al.	2012	Peer-reviewed journal	Canada	Red and white	0.75 L bottled wine	C-G
Rallo	2011	Master thesis	Italy	Passito	0.75 L of Passito di Pantelleria	C-G
Reich-Weiser et al.	2010	Peer-reviewed journal	France	n.s.	0.75 L bottled wine	W-R
Rives et al.	2011	Peer-reviewed journal	Spain	All wine tipes	One million standard natural cork stoppers	P-G
Rives et al.	2012	Peer-reviewed journal	Spain	All wine tipes	One million champagne cork stoppers	P-G

Table 3.7 (continued)

Author	Year	Type of publication	Wine geographic location	Type of wine	Functional Unit (FU)	System boundaries[a]
Rives et al.	2013	Peer-reviewed journal	Spain	All wine tipes	One million cork stoppers and 1 t cork	P-G
Rugani et al.	2009	Conference proceedings	Italy	Red wine	100 kg bulk wine	C-W
Ruggieri et al.	2009	Peer-reviewed journal	Spain	n.s.	1 kg N to vineyard lands	
Sanchez Ramirez	2011	ppt	Italy	Red wine	0.75 L bottled wine	C-G
Schlich	2010	Conference proceedings	Germany, Europe, South-Africa	n.s.	0.75 L bottled wine	C-G
Soosay et al.	2012	Peer-reviewed journal	Australia	Oxford landing wine	n.s.	C-G
Vázquez-Rowe et al.	2012a	Peer-reviewed journal	Spain	White wine	0.75 L bottled wine	C-B
Vázquez-Rowe et al.	2012b	Peer-reviewed journal	Spain	White wine	1.1 kg harvested grape (= 750 ml Rías Baixas wine)	C-F
Vázquez-Rowe et al.	2013	Peer-reviewed journal	Luxembourg	1 Red wine, 1 Sparkling and 1 White wine	0.75 L bottled wine	F-W
Venkat	2012	Peer-reviewed journal	USA	Red and white wine	1 kg of grape	C-F
Villanueva et al.	2013	Peer-reviewed journal	Spain	Ribeiro wine	1.1 kg of grape	C-F
Woodward	2010	Report	South Africa	All wine tipes	Many studies, different FUs	P-G
WRAP	2007	Report	Australia, France, UK	n.s.	0.75 L wine	C-G
Zabalza et al.	2003	Conference proceedings	Spain	n.s.	100 L wine	C-R

[a] *C* cradle, *G* grave, *F* farm gate, *W* winery gate, *B* bottling, *R* retailer, *Co* consumer, *P* packaging production, *n.a.* not available, *n.s.* not specified, *n.d.* no date

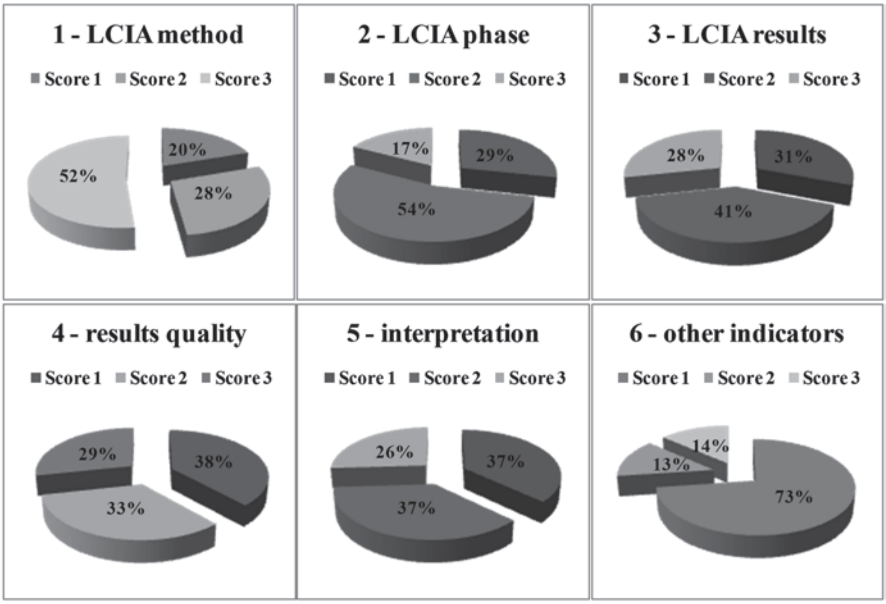


Fig. 3.7 Scores' attribution along the six key issues outlined in Table 3.6 (score 1–3; from 1 to 3 according to the increase of breadth and depth of information provided, see Table 3.6 for further details). The total number of studies for which the scoring was performed is 81

of priority relevance for human well-being, such as "climate", "water" and available "land". As a result, IWCC (Wine Institute 2010) was tested by some scholars for comparing cooperative wineries in central Italy (Pattara et al. 2012a) and for a first application of the OIV-GHGAP system to the wine life cycle (Pattara et al. 2012b). In both cases, a detailed investigation of the advantages and limitations of the protocol and the carbon calculator software was carried out in comparison with conventional LCA-based GWP assessments. The British standard PAS 2050 or the GHG protocol were followed in three other cases (BIER 2010; Cholette and Venkat 2009; Soja et al. 2010).

With regard to the land use issue, this was chosen as a unique indicator in a comparative case study of beer vs. wine production by Mattila et al. (2012b). This is one of the first studies that compares land use and land use change impact indicators in detail, an important issue for all agricultural-based production systems, including wine.

A multi-score perspective in the LCIA of wine was adopted in 52 % of the total of reviewed papers. More than half (22 out of 42) of these studies applied the CML method (Guinée et al. 2002), which proved to be effective in identifying impacts related to a large spectrum of environmental effects at different scales. Ten studies applied the Eco-indicator99 method, three of them comparing it with EPS 2000 and EDIP 96 methods (Cecchini et al. 2006; Cecchini et al. 2005a, b). Two studies applied the IMPACT+2002 method (Cleary 2013; Bengoa et al. 2009) and one the more recent Recipe approach (Arzoumanidis et al. 2013b). The CML method was probably applied because of its maturity (it was developed at the beginning of 2000) and because it embraces up to 10 different impact categories including potentials of global warming, acidification, eutrophication and human toxicity. However, it includes neither land use nor water consumption-related indicators. Since no robust multi-score LCIA method exists, which is capable of including a complete range of impacts of the cause-effect chain, it is reasonable to apply single-score and multi-score methods in combination, strengthening the evaluation of any possible issues and impacts arising from the production of wine.

As regards the LCIA phase in which results were elaborated and presented (see key issue 2 in Fig. 3.2), in 28 % of the cases the inventory results were used otherwise (not for LCIA purposes), and 54 % of the studies presented an LCIA composed of the mandatory phases of classification and characterisation of impacts, with the application of mid-point indicators (from the CML method, as previously observed). Only the remaining 17 % added the normalisation and weighting steps to the characterisation and, in this case, the most frequently used endpoint methods were Eco-indicator99 (Cecchini 2005a, b; Jiménez et al. 2013; Mann et al. 2010; Comandaru et al. 2012; Cecchini et al. 2006; Aranda et al. 2005; Gonzalez et al. 2006; Della Giovampaola and Neri 2004; Catania and La Mantia 2006), IMPACT+02 (Cleary 2013; Bengoa et al. 2009) and Recipe (Arzoumanidis et al. 2013b). The reason why so few studies considered the normalisation and weighting steps is unknown, but one could hypothesise that the authors calculated normalised and weighted scores simply because of the choice of impact methods, which typically provide endpoint targets.

As regards the phases with the greatest impact on the wine production chain, 40 % of the reviewed studies explicitly identified the phase underlying the highest impacts of the wine life cycle, i.e. they performed a contribution analysis. Among these, 34 % demonstrated that impacts are typically generated by packaging production (31 %) during the winery and bottling phase, followed by the agricultural phase (19 %) and transport for distribution to consumers (13 %). This review also shows that several studies did not directly aim at assessing the potential impacts associated with the functional unit of wine (e.g. 0.75 L bottle) but rather products normally included in the wine life cycle, such as natural cork stoppers (Rives et al. 2011, 2012, 2013) or wood boxes for wine bottle storage (González-García et al. 2011a, b).

The majority of the studies presented a good level of granularity in terms of absolute values and a detailed description of the life cycle phases and indicators (41 % with assigned score 2). Nevertheless, 31 % of the studies presented only qualitative analysis, or quantitative but with scarce resolution (little detailed information or only relative contribution results). This is the typical problem of insufficient data being available for a complete LCA study (Ardente et al. 2006; Notarnicola et al. 2007). In certain cases, authors only aimed at informing local stakeholders or companies about the environmental performance of their wine supply chain, and it is usually better in such cases to communicate via ranked scores or percentage numbers (Comandaru et al. 2012; Dodds et al. 2013) Only 28 % of the studies had a high level of granularity in terms of the results, showing quantitative results with wide resolution and transparency, and presenting absolute values through a detailed/site-specific inventory process.

The results' quality is strictly linked to the methodology used for data collection, the depth of the analysis and the representativeness of the elements (site-specific information, local technological or ecological parameters, etc.) included in the evaluated system. The significance of the results could be improved by an attempt to assess the level of uncertainty of the model and the parameters and by testing the robustness and variability of results with a sensitivity analysis. With regard to the outcomes of the scoring attribution for key issue 4, the majority of the studies presented a low level in terms of result quality (38 %), including an incomplete system boundary description and insufficiently representative LCI data. Furthermore, neither an uncertainty nor a sensitivity analysis was carried out, probably because the scope of the analysis was narrowed to assessment of wine life cycle performance only at a preliminary stage (Aranda et al. 2005; Pizzigallo et al. 2008, Carballo Penela et al. 2009; Ruggieri et al. 2009;; Point et al. 2012; Herath et al. 2013) In most cases, the authors used both primary and secondary data from the literature or only a small part of the data for LCI collected from a real case study. For example, in the case of Woodward (2010) the objective was to study and summarise the packaging options available to the wine industry, including the positives and negatives of traditional glass and alternative media. This was based on a review of available research, literature and reports and on the opinions of local and international industry stakeholders.

Finally, 33 % of the studies showed a good level of quality in the results presentation, with more complete system boundary assumptions and representative LCI data. The uncertainty or variability of the model dataset was taken into account but not necessarily evaluated. In effect, only a few quantitative evaluations exist: for example, grapes' yield variability over time (Barry 2011; Bosco et al. 2011) or the amount of fertilisers and pesticides used (Neto et al. 2013).

With regard to the characterisation of uncertainty and variability, only a few authors have reported quantitative assessments. In Kounina et al. (2012), data were mostly collected from the literature, and an uncertainty analysis (Monte Carlo simulation) was performed to assess the variability of uncertain parameters linked to the wine test changes regarding the use of stoppers (impact of wine, cork stoppers, screw caps and replacement rates). Similarly, Cleary (2013) investigated the importance of uncertainty associated with key data input for wine packaging and considered alternatives to conventional single-use glass bottles. The results of this study show that data uncertainty was relatively low.

A high level of result quality was obtained by 29 % of the studies, where an almost complete system boundary (from cradle-to-grave, including details of specific internal processes) was performed, with sufficiently representative LCI data and uncertainty and/or variability evaluations. For example, Mattila et al. (2012b) analysed the impact of uncertainties in LCI and LCIA of wine and beer; for wine detailed uncertainty information was reported mainly for N2O emissions from soil. Moreover, in the Beverage Roundtable (BIER 2010) data uncertainty was assessed by applying the methodology and guidance provided by the Greenhouse Gas Protocol document, namely quantitative inventory uncertainty (WRI and WBCSD 2011). Finally, Bosco et al. (2013) performed a sensitivity analysis to evaluate the robustness of the LCA model and to identify the key parameters and main factors related to the soil organic matter (SOM), whose role is essential in the overall CF (see Sect. 3.3.8). The sensitivity analysis highlighted that the glass bottle was the most important parameter influencing the final results, in agreement with the literature on wine chain LCAs, and for the vineyard phase, the main influential parameters were related to grape yield and the amount of organic matter inputs (cover crops, residues) and, secondly, the mineralisation and humification coefficients.

3.3.7 Interpretation

In the present review, the selected 81 studies were scored from one to three and discussed according to the approach illustrated in Table 3.6 with regard to the "interpretation phase" issue.

In the context of wine LCA, the interpretation phase is typically carried out at different scales of depth and breadth, as the scope of each study and the elaborated LCA results largely differ from one to another. Therefore, we have analysed interpretation as one independent key issue of the LCA methodology, awarding scores from one to three to each of the 81 selected studies (see Table 3.6). In accordance with the principles of ISO 14044, we assigned score 1 to those works that identified only the significant issues based on the LCI and/or LCIA phases, as this is the basic procedure performed by any author. Then, we attributed score 2 if the study reported additional information about the limitations of the analysis and the appropriateness of the definitions and assumptions, allowing for specific recommendations on how to improve the LCA and/or the impact profile in the conclusions section. Finally, the score of three was assigned when the study also included uncertainty-related issues in LCI and/or LCIA data or carried out an evaluation of the completeness and sensitivity of flows and processes, so improving the consistency of the results obtained.

As shown in Fig. 3.7 (key issue 5), studies are similar in terms of scores 1 and 2 (37 % of the studies), suggesting that most authors tended not to advance their interpretation phase from the mere identification of the significant issues and the reporting of limitations and recommendations. In effect, only about a third of the reviewed papers (26 %) present an evaluation of the reliability and robustness of the LCA profile. These latter are mainly investigated by means of a sensitivity analysis on the most relevant issues determined at the beginning of the interpretation (those flows or processes which are more significant in terms of inventory and/or impact on results), such as activities related to packaging (e.g. Barry 2011; Bosco et al. 2011; Catania and La Mantia 2006; González-García et al. 2011b; Cecchini et al. 2006) or transportation (e.g. Amienyo 2012; BIER 2012; Cholette and Venkat 2009; Cleary 2013). Some authors also highlighted the need to improve current LCI practices and explore additional features associated with LCIA and its interpretation by implementing accounting strategies for carbon sequestration and biogenic

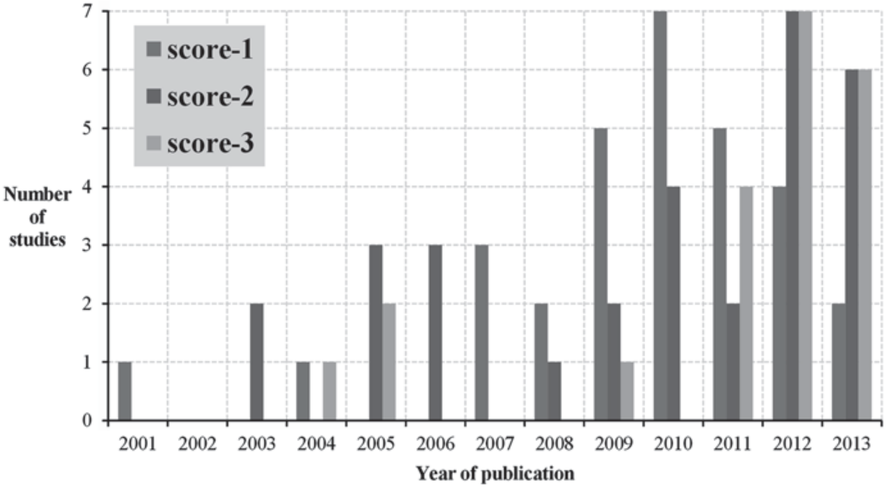


Fig. 3.8 Trend of scores for LCIA interpretation (score 1–3; from 1 to 3 according to the increase of breadth and depth of information provided, see Table 3.6 for further details) per number of studies reviewed. The total number of studies for which the scoring was performed is 81

carbon emissions (Arzoumanidis et al. 2014b; Colman and Päster 2009; Soosay et al. 2012), and changes in SOM (Bosco et al. 2013).

Studies that dealt with uncertainty evaluations or carried out sensitivity analyses and cross-check validations are certainly worthy of further consideration, as they are at the cutting edge in terms of the wine LCA state of the art. They also enable us to understand the extent to which the complexity of the wine LCA interpretation has progressed over time. In this context, the number of studies with a score of three has grown much more lately (2011 to 2013) than the number of studies with a score of one, which have decreased (see Fig. 3.8). This reflects the increased attention of researchers and companies in the investigation of the relevant LCA issues, and the role of the interpretation phase is becoming more and more important for the consistent reporting of information related, in particular, to: (1) the analysis of life cycle hotspots; (2) the determination of weak elements of the methodological approach; and (3) the uncertainty and variability of elementary flows and impact scores.

With regard to item (1), scholars who performed scenario analyses show that strategies of improvement in the use of fertilisers, the lowering of glass bottle weight and the management of transportation of the bottled wine, which are usually the most sensitive parameters of the wine life cycle profile, can provide great benefits in terms of impact reduction (Cleary 2013; Jiménez et al. 2013; Rugani et al. 2013). In contrast, studies which aimed at developing new methodological approaches or calculation tools (referring to item (2)), rather than pure case study of LCA-related analyses, proved that synergies among the use of different approaches exist and can reveal hidden environmental consequences. This is the case, for instance, with the implementation of WF characterisations in LCIA (Herath et al. 2013a, b) and the use of eco-design tools in order to improve the elements raised in the interpretation (González-García et al. 2011b). Finally, it is worth noting that, when authors undertook quantitative uncertainty analyses (e.g. Monte Carlo simulations), the reliability and specificity of the interpretation phase strongly increased (Bosco et al. 2011, 2013; Cleary 2013; Kounina et al. 2012; Mattila et al. 2012b), allowing the scope of the assessment to expand and enrich the geographical and temporal variability of the studies (see, for example, the large spread of results provided in Vázquez-Rowe et al. 2012, 2013). Of course, the opportunity to perform such a robustness evaluation typically depends on the representativeness of the dataset's attributes and on the implementation of site-specific technological and local climate parameters in the LCI stages, whose usage, quality and completeness remain generally quite low in the reviewed studies (cf. Sect. 3.3.6).

Therefore, the most interesting challenge in terms of enhancing the *interpretation* of the wine LCA is to make sensitivity and uncertainty analyses more routinised and operational, and this can be established as long as the case studies and LCI profiles of wine production are readily accessible in the literature.

3.3.8 Critical Analysis

All the seven aspects introduced so far contain an extensive number of methodological elements that comprehensively frame the characteristics of environment-oriented analysis of wine sustainability with the LCA approach. However, the LCA method has rapidly progressed in late years, and not all the most recent and challenging issues of this advance have been dealt with by the scholars concerned.

The worth of the present critical analysis lies in the systematic analysis and update of previous surveys on the wine LCA topic, all of them encompassing issues that belong to the conventional "attributional" LCA approach. Therefore, results of the analysis performed on the 81 studies suggest that other aspects still need to be assessed in the context of wine production or included in future analyses. These belong to methodological issues, which are currently neglected or only marginally treated, despite having been brought to the attention of the LCA community. They can be enumerated as follows:

i. Use of a consequential-LCA (C-LCA) perspective to enhance the evaluation of undesired or unexpected side-effects in the wine market.
ii. Assessment of biogenic carbon and temporal dynamics for carbon emission accounting to develop new characterisation factors for the wine LCIA profile.

With regard to (1), it is worth noting that current developments in LCA methods and databases are strongly focussed on the implementation of C-LCA tools, which aim at relating the effects of one or more choices by studying the environmental consequences of possible (future) changes between alternative product systems, and by modelling the causal relationships originating from the decision to change the output of the product (e.g. Ekvall and Weidema 2004; Earles and Halog 2011; Tillman 2000; Vázquez-Rowe et al. 2014a, b; Weidema 2003, 2006). Moreover, compared with current attributional approaches, C-LCA has been shown to provide some advantageous interpretation frameworks, which show decision-makers the side-effects of specific strategies for policy support (Zamagni et al. 2012). In other words, the C-LCA approach can address the kind of environmental assessment that analyses how biophysical flows of resources, emissions and products and their associated environmental burdens vary in response to changes in (marginal or structural) market implications in a specific life cycle beyond the foreground system (Ekvall and Andræ 2006; UNEP 2011; Vázquez-Rowe et al. 2014a, b).

This relatively novel perspective remains unexplored in wine LCA studies, probably because most authors have typically aimed at modelling the impact of actual (either more or less complex) case studies, rather than advancing pure methodological developments where wine is considered simply for demonstration purposes. It must also be taken into account that the evaluation of wine production with LCA and related tools (e.g. carbon footprint) has a relatively recent history (the first studies date from 2001), and even more recent is the diffusion of the C-LCA concept among practitioners and its effective implementation in LCA guidelines and tools such as databases and software (EC 2010; Ecoinvent 2013).

However, numerous techniques of C-LCA have been developed and tested, in particular for the agricultural production sector, among which are simplified approaches (Schmidt 2008) or more complex methodological combinations of life cycle tools with equilibrium models (Marvuglia et al. 2013; Vázquez-Rowe et al. 2014a, b). In fact, an environmental issue of great relevance and thus one of those most studied with C-LCA is land use, because it reflects the impact of new technologies or strategies in the agri-food sector (e.g. bioenergy production) and their relationship with other production sectors in the market. Therefore, the C-LCA approach represents fertile soil for trans-disciplinary studies in the wine LCA domain on the necessary and potentially hidden aspects of wine-related impacts: for example, the unexpected consequences associated with production cost and retail price changes, which can generate potential rebound effects on the market via a cascade (Binswanger 2001; Hertwich 2005; Rugani et al. 2013; Skuras and Vakrou 2002). With a C-LCA perspective, one could theoretically model such rebound effects with hybrid techniques, analysing the interactions between different actors in the wine life cycle, perhaps after technological modification (e.g. implementation of a new transportation strategy for bulk wine), and then assessing the indirect effects of possible modifications in economic segments other than the wine market (EC 2010; Rugani et al. 2013).

As regards biogenic carbon issues, (2), further in-depth observations could also be made. Hence, the handling of biogenic carbon balances in LCA of agri-forestry systems is of interest, especially in the sustainability and climate science community, as it directly relates to climate change issues. Accounting for CO_2 at each stage of the life cycle offers the advantage of allowing the dynamic modelling of emission and removal, making the analysis consistent with the "polluter pays" principle and the Kyoto rules, which imply that each GHG contribution (positive or negative) should be allocated to the causing agent (Rabl et al. 2007).

Besides the importance of assessing the specific contributions of GHG emissions generated through wine production, it is evident that wineries are starting to face the rebound effects caused by climate change itself on different appellations (Tate 2001; Mira de Orduña 2010). These effects are multiple, affecting different grape varieties in several ways, and in some cases generating opposite effects (Mira de Orduña 2010). More specifically, studies have proved the relationship of climate change with an advance in the harvest dates in several European appellations (Duchêne and Schneider 2005; Ganichot 2002; Jones and Davis 2000; Neman et al. 2001) and varying effects on the quality of the wine, such as higher sugar and alcohol concentrations owed to changes in temperature, climate or radiation (Canova et al. 2012; Jones and Davis 2000; Jones 2007; Jones et al. 2005; Mira de Orduña 2010). Effects of climate change on the wine quality may also have legal implications, in that in the near future modifications of local conditions may not allow the production of fine wines in the regions from which they have traditionally or legally come (Barriger 2011; Ramos et al. 2008). In addition, many studies have linked the alteration of wine phenology to the proliferation of forest fires attributed to the increased warming and aridity in certain areas (Tavşanoğlu and Úbeda 2011; Bento-Gonçalves et al. 2012). For example, oenological consequences described in the literature include the identification of smoke taints in wine (Anderson et al. 2008; Kennison et al. 2011; Simos 2008). Consequently, it appears that in years to come the expansion of these appellation areas may be strongly constrained by the loss of soil quality in neighbouring lands, which implies the reduced carbon stock potential of surrounding areas.

Various mitigating actions could be implemented even by small companies to reduce carbon release (Smyth and Russell 2009) or increase carbon sequestration (Smart 2010). The potential for adaptation and mitigation of climate change in the wine sector, which is highly sensitive to this global issue, does not seem to require substantial changes in the life cycle, such as changes in location, the trellis system (to shade vines with larger canopies), the pruning style and timing (to increase the size of the canopy and/or delay growth), the row orientation (to increase fruit protection from heat and/or sunburn), and irrigation management (if sufficient water is available) (Diffenbaugh et al. 2011). Moreover, it has been observed that additional carbon can be sequestered in the soil during the transition from conventional to organic systems (Venkat 2012). This implies that more farmers may be keen and/or incentivised to shift to organic production in the coming years, contributing to climate change mitigation with more effective tools. Soil management practices, such as residue incorporation and grassing, were also identified as the main factors affecting soil carbon sequestration (Bosco et al. 2013). Above all, pursuing a long-term CF management strategy is a great opportunity for winemakers to contribute directly to climate change mitigation actions at both local and global levels (Rugani et al. 2013).

However, strategies to improve the carbon budget of vineyards are still largely unknown, and an additional challenge will be to reach more consensus on how to assess the contribution from viticulture systems to the release of nitrous oxide, one of the most powerful GHGs (Schultz 2010). As previously mentioned (Sect. 3.3.4), the two stages of viticulture and winemaking are intrinsically related to biogenic carbon balance, being carbon sequestered during vine growth (e.g. Martin 1997; Poni et al. 2006; Soja et al. 2010) and released during the alcoholic fermentation of wine (Notarnicola et al. 2003), respectively. Within the studies evaluated here, some do not explicitly account for biogenic carbon trades and the stalk degradation in soil, because of the difficulties in obtaining a specific spatial estimate without a sampling campaign or validated models (Bosco et al. 2011). However, most authors do not probe the issue because they assume that the CF of wine should only consider fossil-based GHG sources (Barry 2011; Benedetto 2013; Notarnicola et al. 2003; Point et al. 2012; SAWIA 2004; Vázquez-Rowe et al. 2012b), and the commonly accepted principle is that fermentation should be considered negative because of the CO_2 that the vine sequesters (Greenhaigh et al. 2011). Moreover, CO_2 emissions from photosynthesis and must fermentation processes can be easily calculated, but scholars have not included them in the carbon balance because they are perceived as part of the short-term carbon cycle (e.g. CO_2 from wine fermentation, emissions from combustion or breakdown of vine pruning, etc.), as demonstrated in the application of the wine carbon calculation protocol by Pattara et al. (2012).

Nevertheless, from the review of studies that accounted for the contribution of biogenic carbon in their LCI (e.g. Soosay et al. 2012; Vázquez-Rowe et al. 2012b; Colman and Päster 2009; Zabalza et al. 2003), it emerges that biogenic CO_2 and removal activities generated by the carbon stock changes in biomass and soil, and the alcoholic fermentation, should not be neglected. Interestingly, Arzoumanidis et al. (2014b) have pointed to the need for introducing time-dependent carbon accounting in the wine LCA, in order to increase the accuracy of carbon balances for agricultural and bottling phases. Moreover, among the revisions for the new PAS 2050 guidelines (BSI 2011) is the inclusion of GHG emissions and removals from biogenic sources to demonstrate the relevance of considering CO_2 removals and biogenic carbon emissions. However, this change was made to bring the PAS in line with the approach taken in the GHG Protocol Product Standard (WRI and WBCSD 2011) and ISO 14067 (ISO 2013), assuming that biogenic carbon assessment is important for certain products associated with long-term carbon storage, such as perennial crops like vineyards, which can be expected to sequester more carbon than annual crops (CSWA 2009; Carlisle et al. 2009; Kroodsma and Field 2006; Freibauer et al. 2004). It is worth highlighting that the C pool in biomass is considerably smaller ($<1\,\%$ the size) than that in soil (Keightley 2011), and the corresponding vine biomass C pool is removed at the end of the vineyard production period (Bosco et al. 2013).

Future LCA studies in the wine sector will certainly benefit from the implementation of the above methodological progresses, specifically in relation to consequential LCA and biogenic carbon analysis. These could be used to outline a roadmap for more consensual sustainability assessment of wine production supply chains based on LCA, and possibly included in standardised tools or wine-LCA calculators.

3.3.9 Comparative Analysis

In the last few years, several impact assessment concepts have been developed beyond or grounded on LCA, and the environmental footprint concept has attracted increasing interest in both scientific and political communities (EU 2011). Methodological development is quite different, however. Evaluating “comparative analysis" can thus give an overview on the impact characterisation frameworks and models used in the wine LCA, showing the effectiveness of recent implementations across the most traditional and the newest impact categories, with a focus on local impacts and variability, integrated assessment and environmental sustainability analysis. Accordingly, the scoring approach described previously in Sect. 3.3 was useful to quantify the extent to which "Indicator(s)/method(s) other than LCIA" (key issue 6) are involved in the field of wine LCA (see key issue 6 in Table 3.6).

The majority of reviewed studies (73 %) falls within the first category (score = 1), where only conventional LCIA methods are applied (see Sect. 3.3.6 for an in-depth analysis).

In contrast, 14 % of reviewed studies fall within the second category (score = 2), where environmental assessment metric(s) other than those typically included in LCIA methods are applied: in particular, in the present literature review, such metrics are the hydrological water-balance model for measuring the water footprint (Herath et al. 2013a) and the Ecological Footprint (Niccolucci et al. 2008).

As regards the use of the EF for worldwide comparisons, surface measurements expressed in ha rather than gha (global hectares) showed that gha t^{-1} of wine was almost constant over time, this unit being unaffected by changes in yield (Niccolucci et al. 2008). Conversely, results expressed in ha t^{-1} varied over the period considered, demonstrating that local yield variations were accounted for (Niccolucci et al. 2008). A footprint measure reported in gha is globally consistent and can be compared between countries. However, it is unable to track specific changes in local resource management. Instead, actual hectares are an appropriate unit for analysing use and management of local natural resources, but cannot be used for worldwide comparisons.

EF and LCA are complementary in many respects, particularly because LCA has valuable potential for the validation of EF methodology and the development of instruments able to support decision-making both for companies and for public administrations (e.g. for spatial planning). In effect, LCA indicators traditionally applied in the wine sector like GWP, acidification potential, and eutrophication potential can estimate the load of environmental effects on soil, water and atmosphere during the life cycle phases; EF can support the evaluation of the ecosystem surfaces required to generate resources and absorb emissions associated with a unit of product. This information forms the basis for a coherent representation of the environmental profile of wine and the essential content for an environmental label of this consumption product, in either conventional or organic farming.

In the former case, authors have noticed "the grape growing as a land use and wine production as an industry do not have a deleterious impact on depletion of water resources in either region" (Herath et al. 2013a, p. 242). Interestingly, the conclusions of this work are that for agricultural-product WF to be meaningful, the natural variability in the production phase needs to be well accounted for. Given this variability in the impacts of water use on the local water resources, the authors recommend that WF should be assessed at a local level.

In contrast, Niccolucci et al. (2008) compared the EF of conventional and organic winemaking and concluded that the higher footprint of the conventional wine was essentially owed to the agricultural and packaging phases.

Finally, studies with an assigned score of three −*Application of LCIA + other* (*complementary*) *environmental assessment metric*(*s*) for comparative/combination purposes—account for 14 % of the total articles reviewed. In this context, an interesting comparison of different indicators of sustainability is that performed by Amienyo (2012), who ambitiously considered the Life Cycle Sustainability Assessment in the UK beverage sector by coupling LCA, Life Cycle Costings (+ value added analysis) and other specific social indicators (such as consumer health issues, employment and wages, intergenerational issues, child labour, forced labour, etc.). The analysis was conducted for five beverage categories, namely carbonated soft drinks, bottled water, beer, red wine, and spirits and liqueurs. For each beverage category, a standard procedure of LCA was followed by a focus on data quality, impact assessment and interpretation, GWP being the first impact category's indicator evaluated, followed by others such as Primary Energy Demand (PED), abiotic depletion (ADP), acidification (AP), eutrophication (EP), and toxicity indicators. It was observed that the combination of environmental and economic aspects facilitates the identification and comparison of environmental and economic hot-spots in the life cycle (Amienyo 2012).

The novelty of the approach implemented by Amienyo is its attempt to develop a Life Cycle Sustainability Assessment, which has never been proposed before in the wine sector. This is an extremely interesting methodological platform, both as regards the improvement of existing impact evaluation models (scope enlargement) and as regards wine companies (in particular the larger ones) willing to promote their products not only through environmental labels but open to consideration of other pillars related to the concept of sustainability (economy, environment, society).

Other indicators/environmental assessment metrics that have been used or coupled with LCI or LCIA methods are SOM changes (Bosco et al. 2013), ecodesign concepts (González-García et al. 2011a, b) and, related to the latter, the use of a process optimisation simulation (Jiménez et al. 2013), applied to determine impact in terms of the decisions made in the production process.

3.4 Lessons Learnt from LCA: Best Practices for Environmental Improvement in the Wine Sector

The implementation of LCA is oriented to identification of the most significant environmental impacts along the wine production chain. It reveals the "hotspots" of the whole system, in order to optimise the production steps and to support ecodesign strategies.

The review of the international LCA literature, discussed in this chapter, identified the following elements as the main hot-spots of the wine production chain:

- cultivation stage, mainly because of the use of pesticides and fertilisers;
- packaging, mainly because of the production of glass used for bottling;
- electric energy consumption in the winery;

- emission of VOC in the winery;
- distribution, because of fuel consumption in transportation processes.

The cultivation step contributes mostly on Ecotoxicity (ECT), Human Toxicity (HT), Eutrophication (NP) and Acidification (AP). The first two impact categories (ECT and HT) are strictly dependent on the use of pesticides, affecting water and soil toxicity and the human toxicity of workers in the field. The contribution on NP and AP essentially depends on the use of nitrogen and phosphate fertilisers. While NP is caused by water releases of phosphates and nitrates and to air emissions of NO_x and NH_3, AP is due to emissions of NO_x occurring during the fertilisers use.

The production of the glass bottle is one of the phases with the greatest impact in the wine life cycle, as highlighted Ardente et al. (2006). It especially affects energy consumption, Global Warming Potential (GWP), HT, and AP.

Vinification processes significantly contribute to the impact category of photochemical oxidation, because of the emissions of VOC during the alcoholic fermentation. Among these, the most problematic is ethyl alcohol, whose emission ranges between 43 and 71 g/hl in red wine (EPA 1995). Other impact categories affected by the vinification processes are those linked to electric energy production, but they have less impact compared with glass bottle production. In a winery, the stage with the highest energy consumption is the bottling, which accounts for about 60 % of the total energy consumption, followed by the refrigeration phase.

Finally, the distribution phase of bottled wine is also relevant in the environmental profile of wine-related impacts when the winery and the retailer are at some distance from each other. Because the export of wine is increasingly by sea, the consumption of fossil fuels and the transportation means are elements that usually play a significant role in the generation of impacts such as GWP.

Another key issue is the relationship between technology and the quality of wine. Wine production is a complex activity in which technology plays the same important role as grape cultivation and winemaker skills. Although the raw materials are just grapes, yeast and some chemicals, the alternative production processes are highly variable and, as a result, the quality of output wines is highly variable as well. High quality wines have to add more technological steps to their production process and this results in a worsening of the environmental profile when assessed only on the basis of volume or mass (Notarnicola et al. 2010).

Despite the great variety of wines, most wine LCA studies, in particular those with comparative aims, consider as a functional unit a specific amount of product in litres or kilograms, without any reference to the main characteristics of products. This problem could be overcome via the use of other functional units, which could better represent the function of the system, such as a certain alcoholic degree or a certain hedonistic value (Notarnicola et al. 2010). The hedonistic value is an index, which measures the main characteristics of wine based on the traditional describers of the sensory feedback. Other scientifically more robust parameters could be considered in the definition of the functional unit, such as the total dry extract, the reducing sugars, the ash content, chloride and sulphate content, pH, free and total sulphur dioxide, chromatic properties such as luminosity and chromaticity, as defined by EC Regulation 2676/90 and its modifications which determine European

Community methods for the analysis of wines (EEC 1990). Notarnicola et al. (2010) have shown that with more technological production steps, the production of a high quality wine has a worse environmental performance if the comparison is made on the basis of volume or mass. If a different functional unit is considered, the results are completely inverted.

With regard to the vinification typology, it is very difficult to determine which is the most eco-friendly one (e.g. red or white wine). As also observed in Rugani et al. (2013), the variability of the impact associated with the same functional units of different wines worldwide is considerable (red vs. white, organic vs. conventional cultivation strategies). This means that it is extremely difficult to generalise and justify results only on the basis of wine typology; many other factors should be considered that potentially influence the impact associated with the FU. For example, if we consider the grape varieties of Aglianico for red wine and Chardonnay for white wine, the main difference is in their maturity stage, which, in Italy, corresponds to the end of August for Chardonnay and the middle of October for Aglianico. This difference implies that the Chardonnay viticulture needs eight pesticide treatments whereas the Aglianico needs ten of them; the consequence is a 20 % lower use of pesticides, diesel and lube oil in the case of Chardonnay. Nevertheless, the trivial amount of these inputs in the agricultural stage is counterbalanced by the different yields in the two vinifications. In fact, one 0.75 L bottle of red wine typically requires from 1.05 to 1.07 kg of grapes, and one of white wine about 1.2 kg (Notarnicola et al. 2003).

Even within the same vinification, there are technological steps, which increase the energy consumption and also the quality of the wine. In fact, the storage in barriques and the concentration of the must through reverse osmosis require greater resource consumption but, at the same time, they increase the quality of the resulting wines.

With regard to the above issues, below is a summary of the main guidelines to improve the energy and environmental performance of the wine sector.

3.4.1 Agricultural Stage

Integrated pest management and organic agriculture could be an option for the improvement of wine production environmental performance. However, as other studies have shown (Mattsson 1999), organic agriculture is not a better *a priori* solution than conventional agriculture. In the case of wine, the main problems are because of the great difference of yield, which is on average 40 % lower in the organic than in the conventional system, with consequent higher land use and energy and material consumption by the product unit (Nicoletti et al. 2001). Other problems are connected with the type of organic pesticides and fertilisers used: by its nature, manure is assimilated very slowly by plants, causing nitrogen compound emissions during its use; moreover, sulphur and copper sulphate have a more relevant impact in the production phase and a lower one during the use stage. A reduction in the use of these pesticides and consequent better environmental profile of the organic system should be targeted.

Moreover, the environmental profile of the organic production could be further improved by considering other environmental aspects, which cannot be assessed through an LCA; for example, organic farming increases biodiversity on a local scale, improves soil quality and increases the organic component of soils.

3.4.2 Winery

Energy efficiency The reviewed LCA studies show that one of the main impacts in the winery industry is electricity consumption. Improvements in energy efficiency or the use of locally-produced electricity (e.g. through installation of PV panels; Smyth and Russel 2009) can thus play an important role in reducing the energy and environmental impacts of the wine eco-profile.

The employment of plant and processes with high efficiency is also of paramount importance for (indirectly) decreasing energy consumption. The design of energy-efficient plants and the growing use of biotechnology in vinification are just two examples.

The use of biotechnologies is linked to the reduction of the energy consumption in the winemaking process in terms of the yeasts or enzymes used in grape treatments or wine refining to minimise the need for other treatments (Goode 2005).

Traditional filtration with fossil flours implies the problem of their disposal: consequently, new filtration technologies have been tested, e.g. the use of tangential filtration is a promising technology (Baker 2004).

Together with the above-mentioned practices, the implementation of an energy management system in accordance with ISO 50001 (ISO 2011) could result in better environmental and energy performance.

Airborne emissions Carbon dioxide represents the main air emission of the winery. In general, CO_2 is not taken into account in the analyses because it is linked to the natural carbon cycle (see Sect. 3.3.8). However, it is desirable to research for system solutions, which could enable its recovery in order to use it, for example, in carbonic maceration.

With the exception of CO_2, ethanol is the main compound emitted during alcoholic fermentation. Acetaldehyde, methyl alcohol, n-propyl alcohol, n-butyl alcohol, sec-butyl alcohol, isobutyl alcohol, isoamyl alcohol, and hydrogen sulphide are also emitted, but in much smaller quantities. In addition, a large number of other compounds are formed during the fermentation and ageing process as acetates, monoterpenes, higher alcohols, higher acids, aldehydes and ketones, and organosulphides (EPA 1995).

Fugitive ethanol emissions also occur during the screening of red wine, pressing of the pomace cap, ageing in barriques and the bottling process. In addition, small amounts of liquefied SO_2 are always added to the must prior to fermentation or to the wine after the fermentation is completed; SO_2 emissions can occur during these stages, but they are almost impossible to quantify.

Five potential emission control systems for VOC are available: carbon adsorption, water scrubbers, catalytic incineration, condensation, and temperature control, but all systems have their own disadvantages in terms of either low control efficiency or cost-effectiveness, or even overall applicability to the wide variety of wineries (EPA 1995). The only one, which has an emission abatement of about 98 %, is the wet scrubber but, like the other emission control systems, it is not currently used during winemaking because of its high cost. Starting from an ethanol emission of 55 g/hl of wine without abatement systems (EPA 1995), it is possible to reach the following values with the above-mentioned abatement systems: 4.6 g/hl with carbon adsorption, 13 g/hl with catalytic incineration, 0.67 g/hl with wet scrubbers.

The best practice would be the adoption of an abatement system of VOC emissions in the winery, which is compatible with the technology used; the choice of the abatement system must also be made taking into consideration the control of the operating costs.

Recovery of co-products The recovery and reuse of solid co-products—rasps, lees, marc—plays an important role in wines' eco-profile. In life cycle thinking it is possible to skip the burden of their disposal so, in industrial ecology terms, they become a raw material for new processes. The LCA approach allows us to assess the different eco-profiles because of the re-use/recycling of co-products and wastes, and to compare different environmental impacts rising from the above-mentioned options.

The best practice is the complete recovery of co-products and their use in other production chains. However, this should be further investigated in the future if more complex LCA studies are performed for the wine sector (such as those based on consequential LCA approaches; see Sect. 3.3.8), as the use of wine co-products outside the wine market or supply chain might not necessarily imply clean or impact-free recovery.

Wastewater treatment Winery activities represent a source of significant wastewater production, essentially because of the equipment used for cleaning operations and the losses during the processing of raw materials and product movement. Wastewater pollution has an organic and biodegradable nature, for the depuration of which it is possible to use an alternative process to the conventional one called "activated sludge" (Crittenden et al. 2005). Phyto-depuration makes use of the natural capacity of some aquatic plants to absorb substances contained in wastewater, or generated by the degrading action of microorganisms, through the roots (Kadlec and Wallace 2008). The plants that are generated by this process could be used as biomass for compost or energy production. On the other hand, activated sludge technology requires certain energy quantities and sludge needs to be appropriately treated before final disposal.

3.4.3 Packaging

High quality wines are stored in a glass bottle. The literature review shows that glass production is one of the highest contributors in terms of energy consumption and natural resources use.

The other products of wine packaging, such as cork, aluminium capsules and paper labels, generally show very low impacts in all the environmental categories.

As in other sectors, a possible solution is to replace the glass packaging with another material, and in fact, cardboard polylaminate has often been used. However, it is not appropriate for a high quality wine. Wine is a food product, which has no due date. The reason is that temporal evolution elevates the wine's quality. The use of polylaminate packaging entails a wine duration dependent on the duration of the packaging, imposing a restriction unrelated to the nature of the wine. Moreover, results of marketing research show that label design and bottle packaging are key factors in consumer choice (Barber et al. 2006; Lapsey and Moulton 2001). Therefore, glass is likely to continue to play an important role as packaging for wine.

The best practices should therefore be the use of the "design for environment or for recycling" techniques, in order to reduce the specific weight of the materials; the use of recycled materials may be another alternative.

Another approach to reducing environmental impact, practised mostly by companies in new wine-producing countries such as New Zealand (Dodds et al. 2013), is to export the wine in bulk and bottle it in the country of destination, in order to reduce the impact of transport.

Conclusions

A historical overview and an update on wine production opened the chapter, with a special focus on nutritional, cultural and functional aspects associated with the wine supply chain. The analysis proceeded with the presentation of a set of LCA-based methods and the road maps available so far to guide stakeholders (from academia, RDI and industry) in drawing up a life cycle study for wine. Discussion of current guidelines and good practices had the objective of highlighting existing consensus on an international and global scale, and showing the importance of future improvements to facilitate the process of harmonisation between definitions, concepts and approaches. An analysis of the different methods (both at a product and an organisation level) was performed regarding issues such as functional unit, system boundary, allocation and by-product, co-product and waste streams, use of resources and impact categories. A clear result that emerged was that there is no consensus on most of these issues amongst the methods examined.

A comprehensive critical analysis of LCA studies in the wine sector was conducted to ascertain fundamental methodological aspects related to goal and scope, system boundary, FU, data quality and availability, multi-functionality issues, inventory tools and impact assessment approaches, as well as results and research findings. This exercise helped to highlight the criticalities in the methodology and in the management of the wine supply chain and processes, pointing out the strengths and missing items, and generally providing useful insights and relevant recommendations for both LCA analysts and wine producers.

The main issues related to the environmental profile of wine are:

- FU: the majority of the analysed studies consider a mass or volume-related F.U., neglecting issues such as the quality of the product, namely a certain alcoholic level or a certain hedonistic value, especially in comparative studies;
- allocation: starting from the consideration that the production cycles of agricultural or agri-industrial have no more waste to dispose of, but by-products, it is necessary to identify an optimal strategy to deal with multifunctionality in the wine industry;
- the agricultural stage is one of those with the greatest impact on wine production; organic agriculture could be an option for the improvement of the wine production environmental performance, even if it is not an *a priori* better solution than conventional agriculture. Moreover, only few studies take into consideration the vineyard planting, an important factor to consider from an agronomic point of view and for its potential impact on GHG emissions.
- in the winery, improvements in energy efficiency can be achieved through the implementation of an energy control system, in accordance with, for example, ISO 50001:2011;
- consumption phase: not considered in most of the papers because of the negligible environmental impacts;
- glass production for packaging is one of the major contributors in terms of energy consumption and natural resource use: a possible solution is to replace glass packaging with another material or to use recycled glass;
- the provision of glass bottles, field-level emissions from fertilisers, and consumer transport are the life cycle stages proven to cause much of wine's total impact.
- Environmental management programmes that focus on these life cycle stages have a greater potential to result in substantial improvements to wine's environmental profile. In particular, continued research into the potential benefits of bulk transport, bulk packaging, alternative packaging materials, and bottle reuse systems may uncover important environmental improvement options for wine.

Future LCA studies in the wine sector will certainly benefit from the implementation of the above issues related to the sustainability assessment of wine and possibly included in standardised tools or wine-LCA calculators.

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