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The Evolution of Life Cycle Assessment (LCA): Some Guidelines for Future Research in the Wine Sector

Graziella Benedetto¹, Gian Luigi Corinto², Benedetto Rugani³, Ian Vázquez-Rowe³, Enrico Benetto³

¹ Corresponding Author. Associate Professor, Department of Natural and Territorial Sciences, University of Sassari, Sassari, Italy. E-mail: gbenedet@uniss.it. ² Associate Professor, Department of Education, Cultural Heritage and Tourism, University of Macerata, Macerata, Italy. ³ Public Research Centre Henri Tudor (CRPHT) / Resource Centre for Environmental Technologies 6 (CRTE), Esch-sur-Alzette, Luxembourg

Abstract

The international scientific community considers the Life Cycle Assessment (LCA) approach as a key topic in measuring sustainability of economic activities. The purpose of this paper is to focus on future eventual applications of the LCA approach in agricultural economics. In order to sketch some leading drivers for future research, first we will briefly summarize the evolution of the tool from LCA to LCSA, this latter considering more comprehensively the three pillar of sustainability (environmental, social and economic) under the Life Cycle Thinking approach. Then we report a review of the literature about the application of LCA worldwide within the wine industry. The aim is to highlight the used approaches and main economic results, making some critical considerations about the use of this tool and the fields of research that are still scarcely explored.

JEL: Q01; Q540;

Keywords: Life Cycle Assessment (LCA); Viticulture and winemaking; Bibliographical Review

Introduction: background and aims

Nowadays the wine industry is immersed in a worldwide market wherein any country faces external key decision drivers. Amongst these, we can include the movement of supply re-qualification coming by both New

World countries, including Australia, California, New Zealand, South Africa and Chile, being among the leading exporters, and Old World ones where France and Italy are still at the forefront. All these countries have carried out projects for several years to upgrade the quality of production through the adoption of sustainable practices.

The orientation of consumer behaviour towards 'green' wines was enlightened by a survey conducted in 2011 on a sample of 11,312 regular consumers in seven European and non-European countries. According to this (Jones, 2012), the sustainability of production is the 8th ranked criterion for choosing a wine. Moreover, large-scale retailers in the United Kingdom and the United States show increasing orientation in vending wine labels that declare level of CO₂ emissions associated with the life cycle of the product.

In a wide sense, mitigation of global warming effects with reduction of CO₂ emissions is a hot topic in the current international political Agenda, and scholars show an increasing interest in environmental sustainability (Bettencourt & Kaur, 2011). In particular, the Life Cycle Assessment (LCA) approach has become a key reference tool for the international scientific community (Zamagni, 2012). Indeed, LCA is a standardized method to enable the characterization of potential environmental impacts (e.g. global warming potential) generated along the complete life

cycle of a good or service (ISO, 2006).

The possibilities of adopting the LCA methodology in the wine sector seem to be wide and capable of generating abundant results with a more diffused adoption by wine companies and in the whole sector, in order to meet the increasing sustainability patterns and needs of consumer behaviour.

This paper aims at providing a review outlook and tracing some guidelines for future research in the wine sector based on LCA. Accordingly, we have detected among the LCA approaches retrievable in the literature those that have been used in the wine sector, searching some useful starting point for the development of specific research. For this purpose, we first outline the historical development of LCA, reporting key methodological advancements and briefly analysing which of them have been used in the wine sector.

Methodology

This section reports the review design and method along three basic dimensions: 1. review aims and approach; 2. review structure and components; 3. breadth, depth, and 'work done', which can be useful to inform the process of synthesis and its interpretation (Gough *et al.*, 2012). In Figure 1 we enlighten the research question we tried to answer and the approach we followed. This latter is a mix between the explorative and generative methods and allowed us to achieve a two-fold result: (i) to have a synthesis of the state of the art about international knowledge on LCA methodological approaches, generating new conceptual understandings; (ii) to check the international implementation level of LCA in the wine sector, both exploring the international state of the art and generating new patterns for future sectorial research.

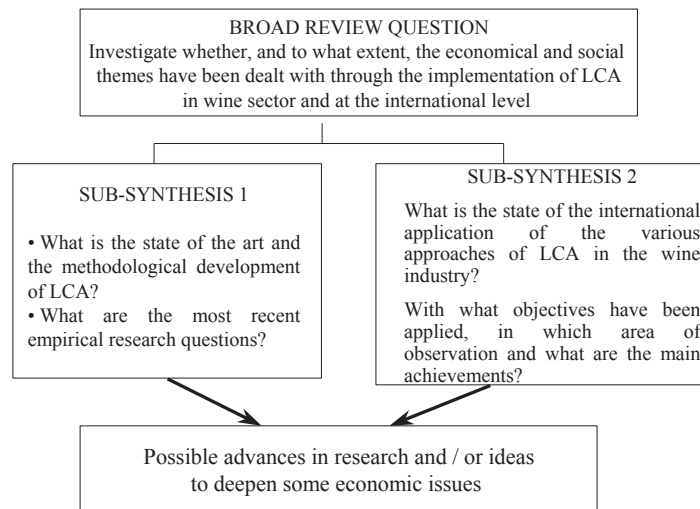


Figure 1. Systematic map of review searching for socio-economic LCA perspective in the wine sector.

Our synthesis has a configurative pattern, aiming at a theoretical research by means of fundamental literature contributions, yet representing main specific studies. Thus, even if

the literature is more extensive than what is reported here, mainly for the second sub-synthesis in Fig. 1, suitable information are given about the very complex and multifac-

ed topics retrievable in the general literature on wine LCA. A narrative synthesis of findings was undertaken.

The expected output is mainly focused on emerging ideas (shared at the international level) and the review is essentially aimed at highlighting possible future developments of the research, based on LCA in the wine sector.

We adopted our traditional 'lens' (i.e. that of the Italian Agro-economic School) not only stressing the technicality of the LCA approach but focusing the attention on the relevance of using LCA in order to better face and manage the complex socio-economic problems of farms, rural society and the productive life cycle surrounding the wine making sector.

In analysing the general and specific LCA literature we adopted a time criterion, following the evolution of the method and its operative implementation, and delving into the convergence between traditional LCA approaches and the economic method. To this goal, we have endorsed the analysis of studies that can better explain the surge of economics in LCA and the eventuality to use this approach also in the wine sector. Our topics of interest were the evolution of different LCA methods, their progressive "contamination" with economic tools, and the applicability in the agro-industrial sector.

We carried out the specific literature review on LCA and in the wine sector through the selection of specialized academic issues regarding two different topics: 1. related to the review of the LCA methodologies in the literature to answer the first sub-research question; 2. related to the review of methodological approaches of LCA applied in the wine sector in order to get to the second sub-research question. The comparison between the two sub-synthesis allows us to generate

ideas for advances in research based on the implementation of LCA in the wine sector. In the first case, the searched keyword was "LCA methodological approach"; in the second the searched keywords were "LCA" and "wine", "CO₂ emission" and "wine".

We considered the following journals, proceedings and books.

- Journals: *Systematic review; The International Journal of Life Cycle Assessment, Journal of Cleaner Production, Journal of Environmental Management, Sustainability, Environmental Engineering Management Journal; International Journal of Agricultural Resources; Journal of Environmental Science and Engineering; Wine Economics and Policy; Journal of Industrial Ecology; Biomass & Bioenergy; Aspects of Applied Biology; Agriculture, Ecosystems and Environment; Journal of Sustainable Agriculture; Journal of International Law; Climate Change, Environmental Science Technology; Journal of Wine Research; Italian Journal of Agronomy;*
- Books: Green Delta; ILCD Handbooks; Some Guidelines of UNEP/SETAC;
- International Conference proceedings: International Conference on LCA; SETAC Conferences; Australian Conference on Life Cycle Assessment; Conference on Efficiency, Costs, Optimisation, Simulation and Environmental Impact of Energy Systems; International Conference on Life Cycle Assessment in the Agri-food Sector; American Association of Wine Economists; Australian Wine Industry Technical Conference; Annual American Association of Wine Economists Conference; ENEA; works of the Italian LCA Network.

Results

The LCA literature: from LCA to LCSA (Life Cycle Sustainability Assessment)

Along with the evolution of the concept of sustainability, which in recent years shows a major focus on the Triple Bottom Line (TBL), comprising economic, environmental and social pillars, a growing interest in the measurement of these three dimensions (both separately and within a single framework) took place (Finkbeiner *et al.*, 2010). Moreover, the LCA approach showed an evolutionary change over time, as depicted in the specific literature dealing with these advancements and changes (Zamagni, 2012; Guinée *et al.*, 2011; Klopffer & Ciroth, 2011; Finkbeiner *et al.*, 2010; Finnveden *et al.*, 2009; Thiesen *et al.*, 2008). These studies constitute an ideal framework to identify the main key research questions and methodological drivers. At the turn of the Sixties and Seventies, when environmental concerns burst into the public opinion, LCA developed as a tool to evaluate the potential environmental impacts of goods and services. In the subsequent thirty years from 1970 to 1990, research was oriented to test methods only through private and unpublished operational studies⁴⁵. The decade 1990-2000 was the period of standardisation, with the issue of the SETAC Code of Practice in 1993, and the intervention of ISO in 1994, which produced the general LCA framework and many impact valuation methods that are still in use. In this second phase, LCA became part of policy and law documents, specifically referring to packaging both in the EU and in Japan (Guinée *et al.*, 2011). This second phase represents also the time for conceptual speculations such as, for example, the first

45. One of the first, frequently mentioned, has been conducted by the Midwest Research Institute (MRI) for the Coca Cola Company in 1969.

attempt to include sustainability concepts in LCA (Andersson *et al.*, 1998) and the birth of the consequential LCA approaches (Weidema *et al.*, 1999; Earles & Halog, 2011).

The decade 2000-2010 has been defined the 'period of elaborations', since the concern on LCA and the necessity to transfer the Life Cycle Thinking principles to real practices, by upgrading data collection, tools and indicators, have increased. This tool became a pole for the EU (see for example the establishment of the European Platform on Life Cycle Assessment) and the USA policies (The Environmental Protection Agency that started promoting LCA).

From a methodological viewpoint, some emerging specific research necessities promoted different approaches, diverging from the traditional LCA in the definition of allocation methods and system boundaries. These are the Dynamic LCA, Spatially differentiated LCA, risk-biased LCA, environmental IO-LCA and hybrid LCA (Guinée *et al.*, 2011).

Nevertheless, all these approaches do face problems of coherence in comparison to the basic standards proposed by ISO⁴⁶. Among these, we can consider the Life Cycle Costing (LCC) approach and the Social-LCA (Guinée *et al.*, 2011, p. 92). As specified by Ciroth & Franze (2009): «LCC is an assessment of all costs related to a product or service, over the entire life cycle, from production over use until disposal... In combination with LCA... LCC can serve to address the economic dimension of sustainability» (p. 2).

For the definition of S-LCA we can refer to Benoit & Mazijn (2009): «A social and socio-economic LCA is a social impact (and po-

46. ISO never aimed to standardize LCA method in detail, arguing that: "there is no single method for conducting LCA", and there is no common agreement on how to interpret some of the ISO requirement (Guinée *et al.*, 2011).

tential impact) assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle encompassing extraction and processing of raw materials; manufacturing; distribution, use; re-use; maintenance; recycling; and final disposal. S-LCA complements E-LCA with social and socio-economics aspects» (p. 37). Today, scholars face the so called Life Cycle Sustainability Assessment (LCSA) decade (2010-2020). A formal LCSA framework was stated (Kloppfer, 2008) as follows:

$$\text{LCSA} = \text{LCA} + \text{LCC} + \text{S-LCA};$$

However, it has been stressed that rather than a 'model' it is a trans-disciplinary integration of models (Guinée *et al.*, 2011, p. 93). The three summed methods have a diverse degree of maturity, in terms of refinement and diffusion of applications. In fact, application guidelines of the environmental LCC (Hunkeler *et al.*, 2008; Swarr *et al.*, 2011; Valdivia *et al.*, 2011) have been published only in recent years. Similarly, the guidelines for the implementation of the S-LCA have been also recently introduced in the literature (Benoit & Mazijn 2009).

A complete application of LCSA that consid-

ers interrelations among the three pillars of sustainability is still lacking.

The wine sector: LCA literature

We built a literature database containing 32 studies which offer a sound description of the-state-of-the-art of the LCA implementation in the wine sector, notwithstanding some involuntary lacks. We still consider it a work-in-progress job, needing continuous updating about operational and theoretical issues in the wine sector. We argue that our work, trying to answer a different and original research question, could be also a useful update of previous recent studies (Petti *et al.*, 2010; Rugani *et al.*, 2013). Fig. 2 shows that the literature on CO₂ emissions rose after the end of the conception and international standardization of the LCA methodology.

The first study on LCA has been issued in 2001 (Nicoletti *et al.*, 2001) and developments raised (Notarnicola *et al.*, 2003) just in Italy (34% of papers analysed), with a constant distribution over time. Surely, the birth in 2006 of the Italian Network of LCA, after the first proposal by ENEA, gave a strong impulse to the diffusion of the LCA method in the agri-food and wine sectors.

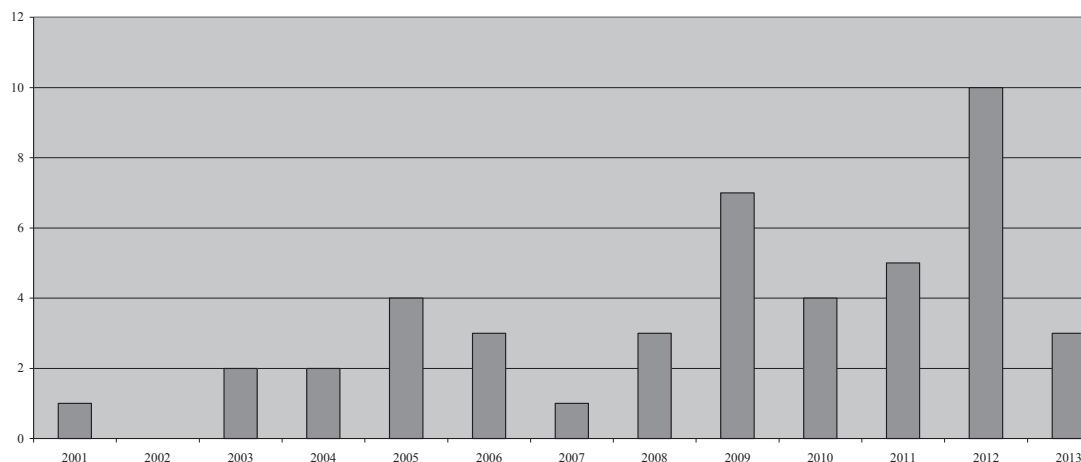


Figure 2. Evolution of studies reporting LCA and CF evaluations in the wine sector.

At the frontline at the beginning of the evolution (Zabalza *et al.*, 2003), we find studies where wine case studies are from Spain, mainly concentrated between 2009 and 2013; followed by cases from USA (Colman & Paster, 2009; Cholette & Venkat, 2009; Venkat, 2012) and UK (Wrap, 2007), which also focused on the topic of transport emissions. Other countries which have provided relevant studies are Australia (SAWIA, 2004;

Soosay *et al.*, 2012), New Zealand (Greenhaigh *et al.*, 2011), Canada (Point *et al.*, 2012), Romania (Comandaru *et al.*, 2012), and Portugal (Neto *et al.*, 2013).

Table 1 shows an overview of the studies including the assessment of environmental emissions in the wine industry, considering the diverse implemented methodologies and their evolution over time.

Tab. 1 - Temporal distribution of wine studies according to the methodology used

	<i>Attributional</i>			
	AP-LCA <i>cradle to gate</i>	AT-LCA <i>cradle to grave</i>	CF	LCA vs others
2001				
2002				
2003	Notarnicola <i>et al</i> (Ch. In Book)	Zabalza <i>et al</i> (Conference)		
2004			SAWIA (report)	
2005		Aranda <i>et al</i>		
2005				
2005				
2006		Gonzalez <i>et al</i> (report)		Petti <i>et al</i>
2006	Ardente <i>et al</i>			
2007			WRAP	
2008				Pizzigallo <i>et al</i>
2008				
2008			Nicolucci <i>et al</i> (EF)	
2009			Carballo Penela <i>et al</i>	Rugani <i>et al</i>
2009			Cholette & Venkat	
2009			Colman & Paster	
2009			Kavargiris <i>et al</i>	
2009		Ruggieri <i>et al</i>		
2010		Gazulla <i>et al</i>		
2010	Schlich (Conference)		Reich-Weiser <i>et al</i>	
2010				
2011				
2011		Bosco <i>et al</i>		
2011			Greenhaigh <i>et al</i> (report)	
2011				
2011				
2012	Vázquez-Rowe <i>et al</i>	Comandaru <i>et al</i>		
2012	Vázquez-Rowe <i>et al</i>	Point <i>et al</i>		
2012				
2012			Pattara <i>et al</i> (b)	Pattara <i>et al</i> (a)
2012				
2012			Venkat	
2012		Arcese <i>et al</i>		
2013	Benedetto			
2013	Neto <i>et al</i>			
2013	Vázquez-Rowe <i>et al</i>			

Along the analysed studies, the attributional LCA, focused on environmental aspect, is the typical approach used, while the system boundaries are most commonly 'cradle to grave' (Fig. 3).

The assessment of environmental emissions associated with the production of a bottle of wine (functional unit 0.75 l) is essentially devoted to:

- identify the critical hot spots of the process (Benedetto, 2013; Arcese *et al.*, 2012; Point *et al.*, 2012; Vázquez-Rowe *et al.*, 2012a; Gazulla *et al.*, 2010; Gonzalez, 2006; Ardente *et al.*, 2006; Petti *et al.*, 2006; Notarnicola *et al.*, 2003; Zabalza *et al.*, 2003);
- communicate the results through eco-labelling (Vázquez-Rowe *et al.*, 2013; Point *et al.*, 2012; Bosco *et al.*, 2011; Carballo Penela *et al.*, 2009; Gonzalez *et al.*, 2006; Ardente *et al.*, 2006).
- There are cases of comparison among different types of wine (white vs. red, premium and medium quality, e.g. Notarnicola *et al.*, 2003) or considering different kinds of process (i.e. conventional vs. organic; e.g. Venkat, 2012; Colman & Paster, 2009; Kavargiris *et al.*, 2009; Niccolucci *et al.*, 2008; Pizzigallo *et al.*, 2008; Gonzalez *et al.*, 2006), LCA of organic wine (e.g. Petti *et al.*, 2006; Rugani *et al.*, 2009), but also among individual companies and cooperatives (e.g. Bosco *et al.*, 2011).

With regard to our research question, most interesting is some works that used LCA for solving strictly economic problems. Schlich (2010), using a partial LCA (i.e. cradle to gate), demonstrates his scientific hypothesis about the existence of an "Ecology of Scale" in the wine industry, i.e. the inverse relation between the ecological impact and the

economic dimension of the firm, where the lower the firm the higher the impact.

Other studies determine relationships between economic productivity and the territorial/operational conditions. For example, Vázquez-Rowe *et al.* (2012a) assessed the wine production in a temporal trend providing time environmental scaling and demonstrating the high dependency on annual crop productivity. Vázquez-Rowe *et al.* (2012b) applied LCA in combination with Data Envelopment Analysis (DEA) providing also insights on economic savings linked to the accomplishment of operational targets. Soosay *et al.* (2012) combined LCA and Value Chain Analysis (VCA) to find the best practice to equilibrate the resources allocation in value industrial chain and consumer's preferences in a selected market segment. Ardente *et al.* (2006) performed LCA and POEMS (Product Oriented Environmental Management System) to foster the dialogue among all the stakeholders and implementing efficient improvement strategies. Finally, Ruggieri *et al.* (2009) carried out an LCA with specific focus on composting systems from a technical, economic and environmental viewpoint.

In any case, those contributions are mainly oriented to the assessment of environmental sustainability.

Discussion and conclusions

Further to the general and simplified review of current literature on wine industry LCA, we propose here an outlook towards the implementation of additional LCA based research lines, which could be also used to improve the rest of the agri-food industry LCA research.

First of all, it is worth noticing that research should be primarily focused towards the development of LCSA, comparing the environmental impact dimension with the social and

economic ones, or use it jointly by applying the S-LCA and/or LCC together with environmental LCA or in an integrated framework (Guinée *et al.*, 2011).

The S-LCA and LCC approaches are particularly interesting in agricultural economics and rural policy because they allow introducing principles and socio-economic mechanisms that the environmental LCA cannot simply afford. Indeed, considering the social constraints of farmers and wine making entrepreneurs is a fundamental concern for Italian agro-economists. In this line, we suggest to contribute to the interdisciplinary debate by exploring the possibilities to incorporate into these two approaches some specific economic and social issues traditionally debated among the agro-economic scholars and professionals (e.g. in the case of the LCC, the problem of calculating the implied costs and the discount rate choice, in the case of S-LCA the multifunctional role played by the viticulture).

At the same time, it is important to highlight the research challenges for the implementation of consequential-LCA. A key issue – linked to the application of LCA and CF – is how the results of the CLCA analyses can be communicated to the final consumer, both at national and international level. Three main topics seem to be relevant, as they can influence both the method implementation and the actual pursuing of predefined aims.

The first is the traceability of emissions within the wine industry, which is associated with the debate about the social responsibility of environmental emissions (Rugani *et al.*, 2013). The second one, strictly linked to the first, is related to the Food Miles debate and the 'green competition' in the world

wine market jointly to the ability/possibility to inform the final consumer. The third issue, instead, pertains to the indirect effects and Rebound Effect (RE) regarding the producer and consumer behaviour of a sustainable wine with low carbon emissions. In fact, the identification and the working mechanism of RE may have important policy implications because the intensity of the CF impacts is crucial when it allows to identify strategies and promote sustainable consumption. In this regard, it would be interesting, also for the wine consumption, deepen the theme of the transmission to the final consumer of the results obtained from the implementation of a low carbon protocol; further investigate the understanding of the environmental label; verify the willingness to pay for a wine with low environmental emissions. Finally, some possible research paths can be identified with regard to the environmental-LCA implementation, mainly oriented to encompass the full system boundaries (from a cradle to grave to a *cradle to cradle*), considering all the activities linked to wine production with a 'zero'-emission/resource consumption perspective. The life cycle of wine should be more comprehensively assessed, by looking at a more complete life cycle of the industry, from vine plantation (including also the production of rooted cuttings) to production of grapes, vineyard activities, winery processing, bottling, distribution, storage, use by final consumer, disposal and recycling. Moreover, the life cycle should include any detailed aspects related to the emissions coming from distribution of pesticides and fertilizers, and transport, as well as the measurement of carbon sequestration by the vineyard (to improve the biogenic carbon balance analysis).

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