CHEMICAL ENGINEERING TRANSACTIONS

VOL. 44, 2015

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

Guest Editors: Riccardo Guidetti, Luigi Bodria, Stanley Best

ISBN 978-88-95608-35-8; **ISSN** 2283-9216

Integrated Sustainability Appraisal of Wine-growing Management Systems through LCA and LCC Methodologies

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Despite the agro-food sustainability issues have been developed and strengthened considerably for a long time, from an operational point of view the sustainable agriculture is still evolving and improvements of production systems are increasingly required to move farmers toward the implementation of agricultural practices environmental friendly and economically viable. Therefore, the evaluation of the economic sustainability becomes a key prerequisite to carry out business operations, while the environmental sustainability assessment can be a strategic tool also to increase the value of product and to structure green-oriented marketing strategies. In this sense, the development of innovative approaches for a systemic and integrated assessment of the sustainability represents an ambitious goal to pursue for scientists, practitioners and for the overall society. In this study, Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) were applied to evaluate, jointly, the environmental and economic sustainability of different vineyard production scenarios in a PDO (Protected Designation Origin) wine-growing area in southern Italy. Two cropping systems (organic and conventional) and two training systems (espalier and gobelet) have been analysed. According to ISO norms 14040 (ISO, 2006a) and 14044 (ISO, 2006b), the study was carried out firstly defining goal and scope of the analysis and, then, considering as “functional unit” 1 ha of planted surface and as system boundaries the agricultural production phases “from cradle to gate”, or rather from plantation to wine grapes harvesting, excluding wine processing, distribution and consumption. The considered life cycle goes from vineyard plantation to disposal (25 y). The same life cycle, as well as the same parameters were considered for the LCC methodology by realizing in this way an inventory of costs complementary to LCA inventory data by adding to the analysis also other costs as farm labour remuneration, land and working capital. The results allowed to ranking the sustainability performances of different wine-growing scenarios.

1. Introduction

Wine production is increasingly interested by several studies aimed to investigate, by means of different methodological tools, its environmental impacts (Christ and Burritt, 2013) linked, among others, to the water use and quality, the energy use, the production of greenhouse gas emissions (Rugani et al., 2013) and the climate change (Mozell and Thach, 2014). The adoption of a more sustainable management of agro-food systems represents certainly a desirable target for environmental urgencies but, in the same time, also the maintaining of farmer’s incomes is a priority, especially in times of economic difficulty. To evaluate the environmental impacts that products and services generate during every stage of their life cycle from planning to disposal (Guinée, 2002), the Life Cycle Assessment (LCA) methodology was largely used in several agro-food sectors as, for example, the fruit production systems (Cerutti et al., 2104). From an economic point of view, the Life Cycle Costing (LCC) is a further tool that allows a detailed assessment of the investments, by considering all costs associated to the project’s life cycle (i.e., acquisition, operation and disposal) (Dhillon, 1989) and by optimizing the economic performances of enterprises (Huppes et al., 2004). Unlike LCA, LCC implementation in agro-food sector is still not widespread and not many researches can be quoted (Iotti and Bonazzi, 2014). According to Jeswani et al. (2010), LCC in combination with LCA can improve the life cycle analysis used in decision-making processes and, recently, an ever-growing attention occurs for joint implementations of these two life cycle methodologies applied in several agricultural systems. For example, olive production is analyzed by De Gennaro et al. (2012) that focus on innovative growing models and by Mohamad et al. (2014) that compare organic and conventional practices. Regarding citrus sector, Pergola et al. (2013) investigate lemon and orange production, while De Luca et al. (2014) explore several quality-oriented systems of clementine crop, in order to assess the environmental and economic sustainability of conventional, integrated and organic management. In this paper, a combined LCA-LCC methodology is applied in order to evaluate, simultaneously, the environmental and economic sustainability of different vineyard production scenarios in a PDO (Protected Designation Origin) wine-growing area in southern Italy. In particular, the study was carried out through the realization of a common data inventory useful to conduct, in a comparable way, the environmental and economic analysis and to combine their results. Furthermore, with respect to the existing literature about wine LCA (Petti et al., 2010), the step forward of this study is the thorough analysis of all agricultural phases in wine-grape production that includes also the unproductive phase and the planting phase, usually excluded in other studies (Fusi et al., 2013).

2. LCA and LCC implementation to the case study

The case study is located in Calabria (South Italy) and in particular in the so-called “Cirò” area in the province of Crotone with a wine production characterized by an excellent quality that represents about 80 % of Calabrian “Protected Designations of Origin” (PDO) wines production regulated by procedural guidelines (MIPAAF, 2011).

In this area, a preliminary territorial survey was carried out in order to highlight the main technical features of wine-grape farms and the main significant differences between the more widespread cropping systems. By synthetizing, the farms structures are mainly obsolete, with traditional techniques and low levels of mechanization, and the most common training systems are “gobelet” or “espalier” (cordon and Guyot) which require high levels of human work and therefore, high production costs. The comparison between conventional and organic productions of two different grapevine-training systems - “Organic-Espalier” (OE), “Conventional-Espalier” (CE), “Organic-Gobelet” (OG) and “Conventional-Gobelet” (CG) - to identify the most environmental suitable solution, represents the goal and scope of the study (i.e. the first step of LCA), according to ISO 14040 (2006a). In terms of system boundaries, the study extends the analysis from cradle to farm gate by considering the whole life cycle of farming plant and also by including planting and orchard disposal but excluding the nursery phase, due to difficulty in collecting data (Cerutti et al., 2014). The above-mentioned four scenarios were analysed considering the whole life cycle of the plant (25 y), distinguished in three main stages (Figure 1): planting stage, training and production stage, and disposal stage.

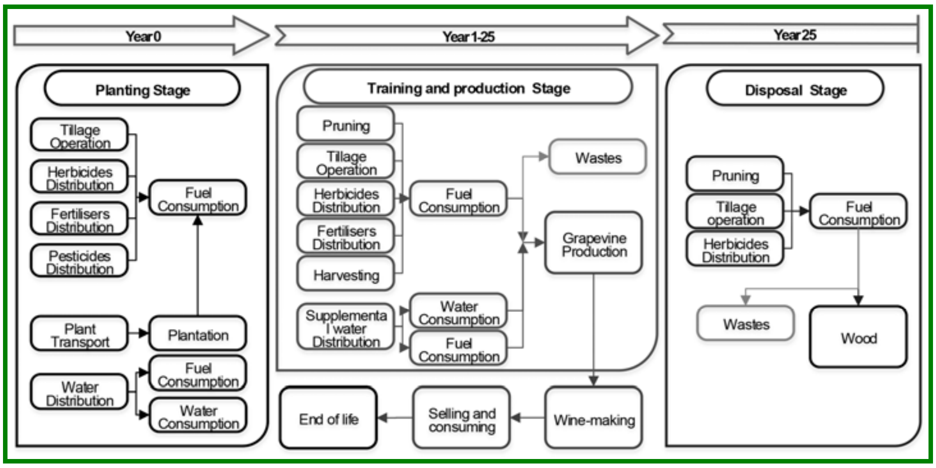

Figure 1: System boundary flow chart

In this study, a Functional Unit (FU) equal to 1 ha of vineyard was chosen, in order to compare the impacts of different growing practices for the same product on production area, according to Cerutti et al. (2015). Primary data of input and output were collected from a sample of 24 ordinary farms through a custom-made questionnaire, built in order to collect technical data and economic ones, to realize an all-inclusive environmental and economic Life Cycle Inventory (LCI). The average data of three-year production (i.e. 2009, 2010 and 2011), were collected and considered in order to reduce the uncertainty degree connected to seasonality and subjectivity of farms management, but also to attenuate production fluctuations and other external factors that could influence the productivity of plants. Data on nitrous oxide and ammonia emissions were estimated according to Ecoinvent (2007); nitrate emissions were estimated according to Brentrup et al. (2000); pesticides emissions were estimated according to Margni et al. (2002) results. Environmental inventory data were processed using SimaPro 8.1 software, Eco-invent V. 3.3 database and, as Life Cycle Impact Assessment (LCIA) method, the ReCiPe was chosen to elaborate results from each scenario analysed. In order to assess the impacts of freshwater consumption, Water depletion indicator was replaced with Pfister et al. (2009) method, a comprehensive impact assessment of freshwater consumption both on a midpoint and endpoint level. Water Stress Index (WSI) represents the midpoint indicator, based on Withdrawal to Availability (WTA) ratio (withdrawals/annual freshwater availability), an index of water deprivation (Berger and Finkbeiner, 2010). Damages to Human Health, Ecosystem Quality and Resources represent the three endpoint impact categories borrowed by the eco-indicator 99 framework, in order to assess the damages in the protection areas human health, ecosystem quality, and resources. To evaluate the affordability of scenarios analysed a joint application of Conventional LCC (ISO, 2008) and financial indicators was carried out. To this end, annual total costs and revenues were calculated by taking into account the entire vineyard life cycle (Strano et al., 2013) and by assuming the same LCA's parameters as well as system boundary and functional unit (De Luca et al., 2014). In particular, the following costs were evaluated: start-up costs (design and plantation cost), operating costs associated to each production phase (training, increasing, constant and decreasing phase) and disposal useful (considering expenses and revenue arising from the disposal). To calculate these costs each environmental input and output considered in LCA analysis (i.e. each single component of data inventory) was monetized by multiplying the average quantity (of the three-year period) by its unit price referred to the last year. In addition, to determine the amount of total cost, other cost items were considered: farm labour remuneration, land and working capital and fixed costs (shares of maintenance and insurance, interests on advance capital, taxes and services). The annual total revenues, associated to the whole life cycle, were determined considering the selling of grapevines production and the same market price for each scenario, referred to the last harvesting campaign, equal to 0.50 € Kg^{-1}. The revenues were evaluated both by including public subsidies and by excluding them. Once the cash flows of the investment were identified, we proceeded to actualize them by applying a discount rate equal to 1.8% considering the low risk and long-term of agricultural investments. Finally, to assess the profitability of the investments, financial indices were used: the Net Present Value (NPV), the ratio between Benefits and Costs (B_0/C_0) and the Internal Rate of Return (IRR).

Table 1: Life Cycle Impact Assessment (LCIA) results

Impact Categories	Unit	OE	OG	CE	CG
Climate change (GWP)	kg CO_2 eq	61,665.55	60,955.91	65,318.03	66,044.56
Ozone depletion (ODP)	kg CFC-11 eq	2.17E-03	2.16E-03	8.84E-03	1.10E-02
Terrestrial acidification (TAP)	kg SO_2 eq	681.20	680.34	690.48	704.24
Freshwater eutrophication (FEP)	kg P eq	15.46	15.40	9.79	11.14
Marine eutrophication (MEP)	kg N eq	54.84	54.81	57.19	58.80
Human toxicity (HTP)	kg 1,4-DB eq	31,373.14	30,805.94	13,229.43	15,135.85
Photochemical oxidant formation (POFP)	kg NMVOC	215.82	216.04	223.26	231.72
Particulate matter formation (PMFP)	kg PM10 eq	134.84	134.67	137.78	142.22
Terrestrial ecotoxicity (TETP)	kg 1,4-DB eq	6.83	6.58	6.50	7.20
Freshwater ecotoxicity (FETP)	kg 1,4-DB eq	494.44	482.78	264.47	295.64
Marine ecotoxicity (METP)	kg 1,4-DB eq	543.89	532.13	274.74	307.98
Ionising radiation (IRP)	kBq U235 eq	3,723.35	3,668.13	4,378.97	4,576.21
Agricultural land occupation (ALOP)	m^2a	3,741.56	11,678.96	3,755.39	11,761.78
Urban land occupation (ULOP)	m^2a	299.63	383.51	514.33	616.71
Natural land transformation (NLTP)	m^2	4.61	5.08	4.76	5.57
Metal depletion (MDP)	kg Fe eq	7,497.01	7,473.16	3,210.75	3,753.87
Fossil depletion (FDP)	kg oil eq	5,547.73	5,517.06	6,575.55	7,115.71
Water Stress Index (WSI)	m^3	9,401.29	8,945.19	9,711.84	10,687.68
Damage to Human Health (HH)	DALY	8.90E-03	8.42E-03	6.86E-03	7.47E-03
Damage to Ecosystem Quality (EQ)	$PAF*m^2yr$	8356.99	7943.15	7944.85	8736.83
Damage to Resources Availability (RA)	MJ surplus	26390.45	24989.48	25421.13	28216.71

3. Results and discussion

For each scenarios analyzed the results of LCIA are showed by distinguishing the different impact categories of ReCiPe method (Table 1). In terms of Climate Change, the OG scenario has the best performance while the worse is attributable to CG scenario. In particular, within this category, the most Greenhouse Gas Emissions were generated during Training stage (about 50%) and Planting stage (about 30 %), due to the fertilizers distribution and the use of tractors. Overall, the conventional scenarios get the worst results for most of the categories, due the use of chemical products for fertilization and the pest control, with the exception of Freshwater eutrophication, Human toxicity, Freshwater ecotoxicity, Marine ecotoxicity and Metal depletion indicators. For these latter categories, the organic scenarios show the worst performances, due to the large amount of copper distribution for pest control. Agricultural land occupation represents the impact category in which the training system makes the difference, since the "gobelet" systems entail a significant use of wood poles for the support of training system. In terms of water assessment, the implementation of Pfister et al. (2009) method shows that OG scenarios are the best performance even if the gap with other scenarios are not significant (Figure 2). The incidence of agricultural operations on water deprivation is variable depending on the life cycle stage. The most impacting stage is represented by the production stage (about 70 % of total impact), followed by the plantation stage which has an incidence variable among 10 % and 20 % (in conventional scenarios). The building of support systems has the bigger water impact, due to the large use of water during the materials production (water for energy production and for metal cooling). Furthermore, the production of chemical fertilizers also has a high impact but this is limited to the plantation stage. In the training stage and especially in production stage the most impacting operations are Pest control and Irrigation. In particular, the first one depletes a large amount of water due to the contamination generated by the industrial production. In disposal stage, the removal operations of training systems represents about 98 % of impact, but this stage influences only about 0.2 % of total life cycle.

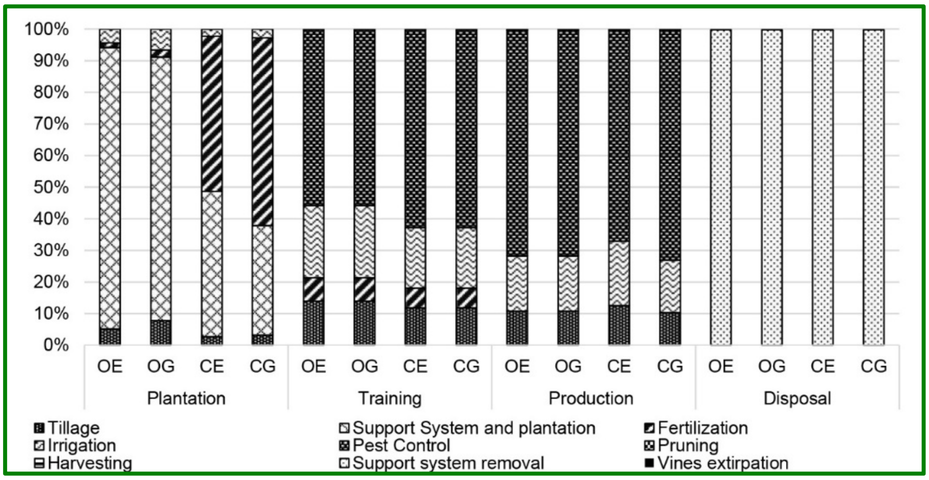

Figure 2: Water impact contribution of farming practices for single stage of life cycle

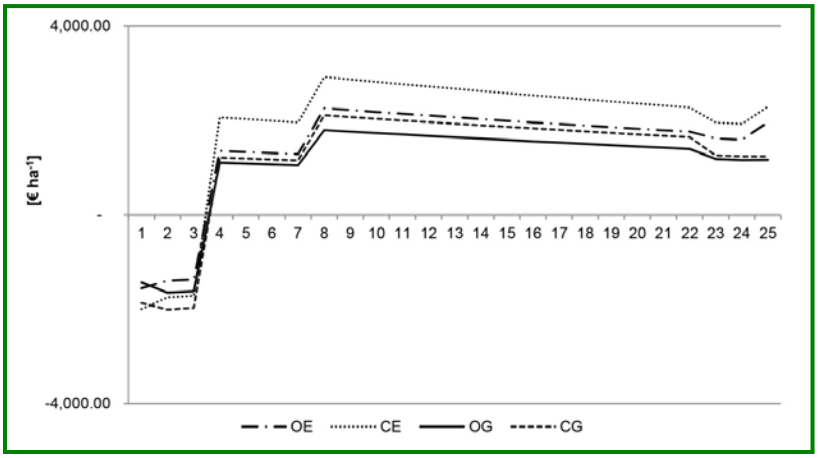

Figure 3: Net cash flows of the entire vineyard life cycle

Referring to the economic analysis, figure 3 shows for each scenario the net cash flows of the entire grapevines life cycle. The CE scenario records the best performance in terms of income (i.e. the revenues totally cover the costs) starting from the 4^{th} year, due both to the higher yield and greater efficiency of production factors. In other words, the net profits are able to repay the initial outlay and remunerate the invested capital. On the contrary, the OG scenario represents the worst scenario as it is the most expensive system (3,321.36 € ha^{-1} y^{-1}). The results derived from the financial indices assessment are reported in table 2. By including subsidies, findings reveal a positive NPV values and B_0/C_0 rate for all scenarios. Similar results are recorded by analysing the return on investment in terms of IRR. In particular, the CE scenario has the best performances, proving the profitability of the investment project in terms of returns on invested capital. Likewise, in absence of subsidies this scenario remains the most profitable than the others, for which negative values are recorded.

Table 2: Results of the financial analysis

Scenarios	Including subsidies			Excluding subsidies		
	NPV (€ ha^{-1})	B_0/C_0	IRR (%)	NPV (€ ha^{-1})	B_0/C_0	IRR (%)
OE	12,536.70	1.15	4.56	-4,454.56	0.95	< 1,8
CE	24,923.49	1,31	6.85	11,930.17	1,15	4.34
OG	5,309.05	1.06	3.16	-11,682.21	0.86	< 1,8
CG	8,998.20	1.10	3.93	-3,995.11	0.95	< 1,8

Despite the difficulty to equate different sustainability aspects, a comparisons in terms of "percentage distance" of each scenario from the best one (Table 3) can be useful to point some significant information. In particular, for LCA and water assessment, the ranking was obtained by calculating the average of gaps between the specific indicators. As consequences, the CE scenario is the most environmentally performing, as well as for the LCC and financial analysis. In conclusion, by considering the findings of this study, a twofold suggestion can be provide. On the one hand, it could be suitable the use of recycled material for the training structures, the reduction of pesticide distributions by means innovative formulates and an optimization of fertilisers distribution in order to reduce the incidence of environmental impacts. On the other hand, the reduction of harvesting and pruning costs through the mechanization, as well as the reduction of costs related to the chemical inputs could represent useful recommendations for the improvement of farm management.

Table 3: Comparison of environmental and economic results (percentage distances)

Scenarios	LCA		Water assessment		LCC and financial indices					
	ReCiPe	Ranking	Pfister method	Ranking	NPV	Ranking	B_0/C_0	Ranking	IRR	Ranking
OE	+4.69	II	+8.83	III	-49.70	II	-12.21	II	-33.43	II
OG	+18.13	III	+3.11	II	-78.70	IV	-19.08	IV	-53.87	IV
CE	Best	I	Best	I	Best	I	Best	I	Best	I
CG	+27.94	IV	+10.24	IV	-63.90	III	-16.03	III	-42.63	III

4. Conclusions

The aim of this study is to propose a combined LCA-LCC analysis to assess the environmental and economic performance of different wine-growing management systems in southern Italy. In particular, through a common life cycle inventory, which includes technical and economic primary data on input and output of production systems life cycle, the ReCiPe impact categories (with a focus on water assessment) and the net cash flows associated to specific financial indices were taken into account. The results were useful to highlight the main hotspots in wine-grape production systems linked to life cycle stages and to specific agricultural operations in order to suggest improvements for a more sustainable management.

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