Environmental impact and energy demand comparison of vineyard by the life cycle assessment methodology

Priya Devasirvatham[1,2]✉, Carles M. Gasol[1,2], José Dorado[3], César Férnandez-Quintanilla[3]

[1]Inèdit Innovació SL, Research Park of the Universitat Autònoma de Barcelona, Campus UAB, 08193, Bellaterra, Catalonia, Spain.
[2]SosteniPrA (ICTA-IRTA-Inèdit), Institute of Environmental Science and Technology (ICTA), Universitat Autònoma de Barcelona (UAB), Campus UAB, 08193 Bellaterra, Barcelona, Catalonia, Spain.
[3]Institute of Agricultural Sciences (ICA), CSIC, Serrano 115b, 28006, Madrid, Spain.
✉ pdevasirvatham@email.wm.edu

Summary: This research compared five viticulture management scenarios, ranging from intensive (chemically and mechanically) to low-input, and two organic management methods. It analysed the environmental impacts from each system using Life Cycle Assessment for two years. The main comparison was done using as functional unit one kilogram of grapes; however, a comparison per hectare was also included to more accurately represent how the systems interacted with the environment. The results show that the production and application of mineral fertilizers had a higher environmental impact than any other input or process. In scenarios where mineral fertilizer was not applied, electricity used to pump groundwater for irrigation created the highest impact. Regarding the weed management processes, the application of glyphosate created more impact than any other related process. The intensive management scenarios generated more impact than the organic or low-input scenarios; they also produced a higher yield, with the exception of Scenario Organic 1, which demonstrated an unusually high yield for an organically managed plot.

Keywords: viticulture, LCA, weed management, pesticides, fertilizer.

1. INTRODUCTION

Major enemies of the vines, apart from climatic factors, are diseases, pest insects and invasive weeds. In order to combat them a set of pesticides are being applied according to every specific problem. Recently, studies have been published in regards to the carcinogenic side effects and toxic by-products of such chemicals and the potential harm they could cause to humans and the environment (EPA, 2016; WHO, 2016). In response, wine growers and producers have begun the switch to alternative agricultural methods such as organic and integrated management. Organic farmers use a variety of mechanical procedures and regulated organic and inorganic products to manage these pests. So far, few environmental comparison studies have been conducted on weed management methods (Villanueva- Rey et al., 2014; Rouault et al., 2016). This study seeks to quantify, using Life Cycle Assessment (LCA), the major environmental impacts caused by different vineyard production systems utilized in the region D.O. (Denominación de Origen) Madrid. The main goal of this study is to shed light on the environmental impacts of weed management practices in viticulture in Spain.

2. MATERIAL AND METHODS (ISO, 2006a; ISO, 2006b)

2.1. Functional Units. The main functional unit (FU) was one kg of grapes. A secondary FU, one hectare of land, was also included in the study to better represent how the different systems interacted with their environment.

2.2. System Boundaries. The system under study considered all agricultural activities that took place on the vineyard during the two years of the study including fertilization, pest management and other field operations. The use, production, repair and maintenance of all agricultural machinery was also included. Excluded from the analysis were the vine nursery stage, vineyard infrastructure, human labour, and any activity that took place upon the grapes leaving the property.

2.3. Management Scenarios. The Chemically Intensive (*CI*) scenario involved the greatest quantity of agrochemicals applied. The Low Input (*LO*) scenario involved a minimal amount of chemical and mechanical inputs. The Mechanically Intensive (*MI*) scenario used some agrochemicals but relied on mechanical operations to manage weeds. The two Organic scenarios (*O1* & *O2*) only used organically regulated chemicals and products. In *O1* the row and inter-row area was tilled whereas in *O2*) was maintained with a natural plant cover. The scenarios are described in greater detail in Table 1.

2.4. Data Acquisition. All primary data was taken from an experimental drip-irrigated vineyard located in Colmenar de Oreja, Madrid. The vineyard is located in the «Denominacion de Origen» of Madrid in the subregion of Arganda. It is located at an altitude of 720 m above sea level. The soil is a mixture of clay and limestone and has a pH range of 7.5-8.5. Average annual rainfall is 300 mm. The vines (var. Tempranillo) are planted 1.2 m apart and in rows 2.4 m wide and 32 m long.

2.5. Direct Emissions. Emissions from fertilizers were calculated from a mixture of sources. Nitrogen emissions were based on IPCC 2006 principles and the following equation:

$N_2O = 44/28 * (0.01 (N_{tot} + 14/17*NH_3 + 14/46*NO_x) +0.0075 * 14/62*NO_3)$, where N_{tot} is the total nitrogen found in the fertilizer (IPCC, 2006). NO_x and NH_3 emissions from the nitrogen-based mineral fertilizer were calculated using relevant emission factors from the European Environmental Agency Air Pollutant Emission Inventory Guidebook 2016 (EMEP/EEA, 2016b). NO_X emissions from organic, compost-based fertilizer used the same assumptions as the mineral fertilizer. However, NH_3 emissions were calculated using the following equation (EEA, 2013): kg NH3N= kg $N{\cdot}ha^{-2}$ * %TAN * EF spreading

For EF spreading an average value was used because no relevant emission factor for composted poultry manure was available (EEA, 2013). The value for % TAN was derived from a publication on using manure as compost (UMN, c2017).

Previous research indicated that most pesticide emissions are released to the soil. We assumed that 94% of emissions went to the soil and the remaining 6% went to the air (Fantke 2012).

Direct emissions from field operations such as diesel consumption by agricultural machinery were calculated using the Ecoinvent database (2007). Machinery use was calculated with the following equation (Nemecek, 2004): $AMF=W*OT*LT^{-1}$, where AMF corresponds to the amount of machinery used on the field when W is the weight of the machinery, tractor, or equipment used (kg), OT is the time spent for each operation, and LT is the lifetime of the machinery.

2.6. Life Cycle Inventory. Tables 1 and 2 provide an inventory of inputs and outputs for the different management scenarios.

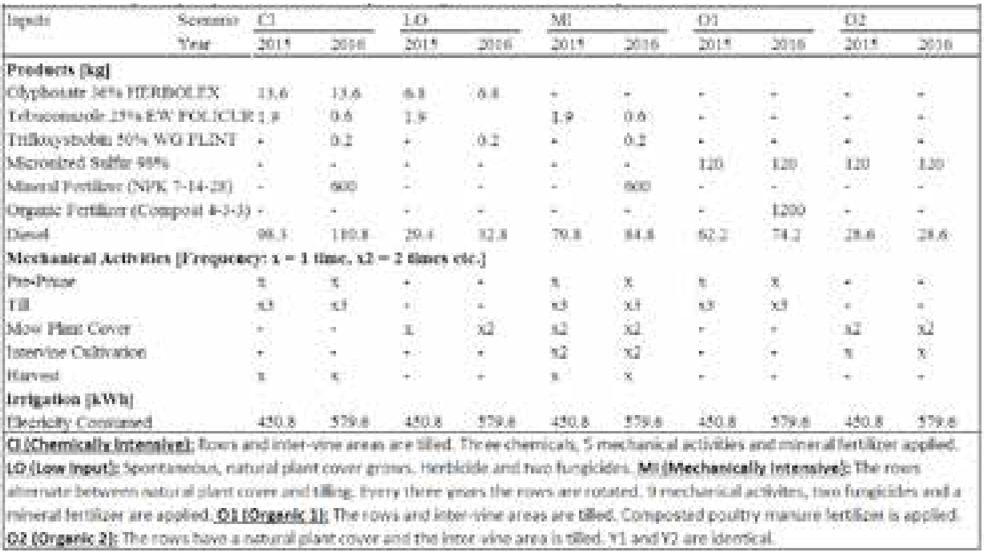

Table 1. Inventory of inputs per hectare for all vineyard management scenarios for the years 2015 and 2016

Inputs	Scenario	CI		LO		MI		O1		O2	
	Year	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Products [kg]											
Glyphosate 36% HERBOLEX		13.6	13.6	6.8	6.8	-	-	-	-	-	-
Tebuconazole 25% EW FOLICUR		1.9	0.6	1.9		1.9	0.6	-	-	-	-
Trifloxystrobin 50% WG FLINT		-	0.2	-	0.2	-	0.2	-	-	-	-
Micronized Sulfur 98%		-	-	-	-	-	-	120	120	120	120
Mineral Fertilizer (NPK 7-14-28)		-	600	-	-	-	600	-	-	-	-
Organic Fertilizer (Compost 4-3-3)		-	-	-	-	-	-	-	1200	-	-
Diesel		98.3	110.8	29.4	32.8	79.8	84.8	62.2	74.2	28.6	28.6
Mechanical Activities [Frequency: x = 1 time, x2 = 2 times etc.]											
Pre-Prune		x	x	-	-	x	x	x	x	-	-
Till		x3	x3	-	-	x3	x3	x3	x3	-	-
Mow Plant Cover		-	-	x	x2	x2	x2	-	-	x2	x2
Intervine Cultivation		-	-	-	-	x2	x2	-	-	x	x
Harvest		x	x	-	-	x	x	-	-	-	-
Irrigation [kWh]											
Electricity Consumed		450.8	579.6	450.8	579.6	450.8	579.6	450.8	579.6	450.8	579.6

CI (Chemically Intensive): Rows and inter-vine areas are tilled. Three chemicals, 5 mechanical activities and mineral fertilizer applied. **LO (Low Input):** Spontaneous, natural plant cover grows. Herbicide and two fungicides. **MI (Mechanically Intensive):** The rows alternate between natural plant cover and tilling. Every three years the rows are rotated. 9 mechanical activities, two fungicides and a mineral fertilizer are applied. **O1 (Organic 1):** The rows and inter-vine areas are tilled. Composted poultry manure fertilizer is applied. **O2 (Organic 2):** The rows have a natural plant cover and the inter vine area is tilled. Y1 and Y2 are identical.

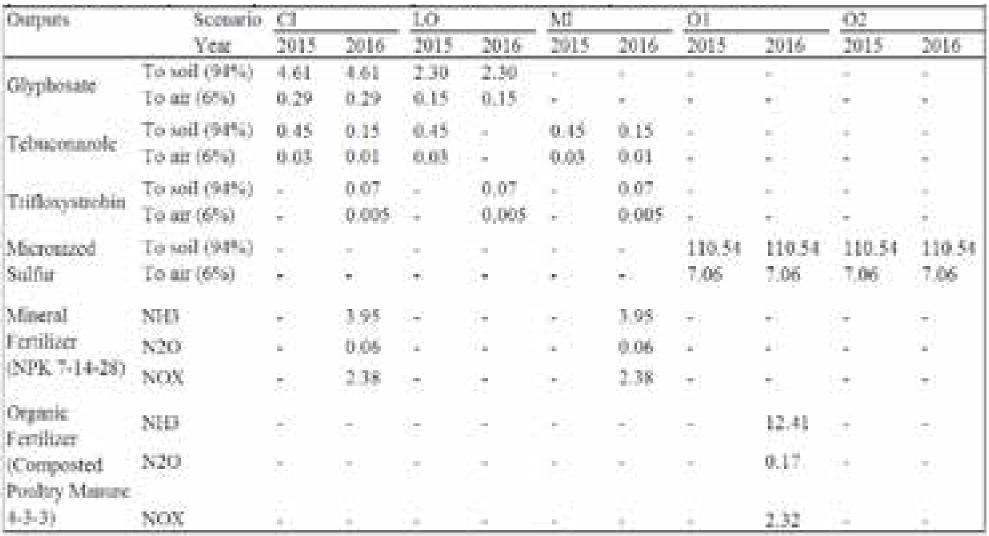

Table 2. Inventory of outputs in kg/ha. Emissions resulting from application of phytosanitary and nutrient management products on the vineyard in all pest and weed management scenarios for the years 2015 and 2016

Outputs	Scenario	CI		LO		MI		O1		O2	
	Year	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Glyphosate	To soil (94%)	4.61	4.61	2.30	2.30	-	-	-	-	-	-
	To air (6%)	0.29	0.29	0.15	0.15	-	-	-	-	-	-
Tebuconazole	To soil (94%)	0.45	0.15	0.45	-	0.45	0.15	-	-	-	-
	To air (6%)	0.03	0.01	0.03	-	0.03	0.01	-	-	-	-
Trifloxystrobin	To soil (94%)	-	0.07	-	0.07	-	0.07	-	-	-	-
	To air (6%)	-	0.005	-	0.005	-	0.005	-	-	-	-
Micronized Sulfur	To soil (94%)	-	-	-	-	-	-	110.54	110.54	110.54	110.54
	To air (6%)	-	-	-	-	-	-	7.06	7.06	7.06	7.06
Mineral Fertilizer (NPK 7-14-28)	NH3	-	3.95	-	-	-	3.95	-	-	-	-
	N2O	-	0.06	-	-	-	0.06	-	-	-	-
	NOX	-	2.38	-	-	-	2.38	-	-	-	-
Organic Fertilizer (Composted Poultry Manure 4-3-3)	NH3	-	-	-	-	-	-	-	12.41	-	-
	N2O	-	-	-	-	-	-	-	0.17	-	-
	NOX	-	-	-	-	-	-	-	2.32	-	-

2.7. Impact Category Selection. The life cycle impact assessment (LCIA) was performed using Recipe H Midpoint for the following impact categories: Climate Change (CC), Ozone Depletion (OD), Terrestrial Acidification (TA), Freshwater Eutrophication (FE), Marine Eutrophication (ME), and Water Depletion (WD). Additionally USEtox method was used to calculate Human Toxicity, both Cancer (HT-C) and Non-Cancer (HT) and Freshwater Ecotoxicity (FET). CEDA methodology was used to calculate the Energy Demand (ED) of each scenario. Simparo 8.2 was the software utilized to compute the results. (ISO 2006a, ISO 2006b).

3. RESULTS AND DISCUSSION

3.1. Overall analysis. When analysing the overall impact using an hectare as the Functional Unit (FU), the order of scenarios, from the lowest to the highest, was: *O2, LO, O1, MI, CI*. Scenario *O2* performed the best in the categories FE, HT, and HT-C. Scenario *LO* showed the lowest impact for CC, OD, TA, WD, ME and ED while scenario *O1* had the lowest impact on HT, HT-C and FET. The scenario *CI* performed the worst for all impact categories. When the impacts were analysed using one kg of grapes as the FU, the results changed due to the contrasting grape production levels from each scenario (Table 3). In this case the order of scenarios, from the lowest to the highest, was: *O1, LO, O2, MI, CI. MI* and *CI* were the two most impacting scenarios, with *MI* affecting particularly to CC, TA, ME, WD, and HT and *CI* affecting to FE, HT-C and FET. The scenario *O2* has the highest value for OD and ED. Both scenarios *LO* and *O1* have intermediate and low impact across all impact categories. *LO* shows the lowest values for CC, OD, TA, and ED while *O1* shows the lowest impact for FE, WD and FET. *O2* shows the best results for ME, HT and HT-C.

Table 3. Grape production (tn ha^{-1} yr^{-1}) for each scenario

Scenario:	CI	LO	MI	O1	O2
2015	12.7	7.7	8.1	10.4	7.1
2016	14.7	12.2	13.5	18.9	8.3

3.2 Analysis per scenario. Figure 1 & 2. Differential contribution to the various environmental impacts in two contrasting scenarios: Chemically Intensive (CI) and Organic with plant cover (O2).

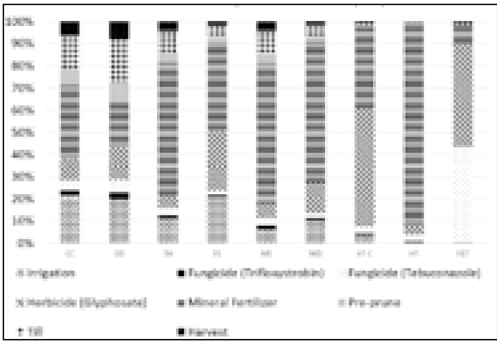

Figure 1. Scenario CI. Impact contribution per process

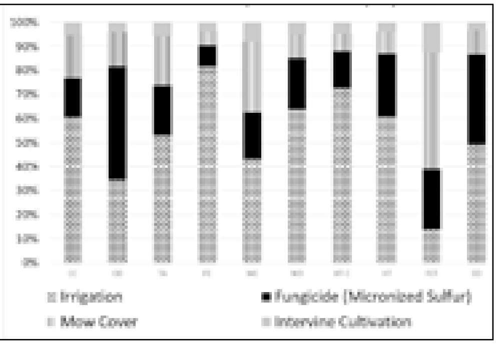

Figure 2. Scenario O2. Impact contribution per process.

In the Chemically Intensive (*CI*) scenario, mineral fertilizer application was the process with the greatest influence. It was the main contributor to CC(33%), TA(60%), FE(39%), ME(63%), WD(64%) HT-C(54%) and HT(92%). Fertilization, irrigation and soil tillage had similar effect

(~20%) on OD. Irrigation and fertilizing have the highest effect on ED (30 and 24% respectively). The application of the herbicide glyphosate dominates the category HT-C (54%) and shares impact with the fungicide tebuconazole for the category FET(46% and 43% respectively).

In the Low Input (*LO*) scenario, irrigation was the most impacting process, with 37-66% impact in the categories CC, OD, TA, FE, ME, WD and ED. Glyphosate production and application had a strong effect on HT-C (79%) while tebuconazole greatly affected HT (43%) and FET(58%).

In the Mechanically Intensive (*MI*) scenario mineral fertilizer application was the input with the greatest environmental burden. Its impact ranged from 37-95% in all impact categories except for OD, FET and ED which are respectively impacted by irrigation (25%) and tebuconazole application (81%). The ED comes mostly from irrigation (35%) but fertilizer still contributes significantly (27%).

In the Organic 1 (*O1*) scenario the environmental burdens were spread among the varying inputs. Irrigation affected CC (38%), FE (62%), WD (40%), HT-C (52%), HT (46%) and ED (36%). Tillage greatly impacted FET (51%). Spreading of organic fertilizer contributed to TA (64%) and ME (68%). Finally, the application of micronized sulphur was the highest contributor to OD (32%) and a high contributor to ED (27%).

In the Organic 2 (*O2*) scenario, irrigation was the process with the greatest environmental impact. It contributed to CC (61%), TA (53%), FE (82%), ME (43%), WD (64%), HT-C (73%), HT (61%) and ED (49%). The application of micronized sulphur impacted OD (47%) and ED (37%) while mowing the natural plant cover affected FET(48%).

3.3. General conclusions. Applied NPK fertilizers had a greater impact than any other process across all impact categories except for Freshwater Ecotoxicity (FET). Although nitrogen based fertilizers are generally considered necessary, the consequences are the release of GHGs N_2O, NH_3 and NOX to the air.

The irrigation process was identified as a hot-spot and a high contributor in all the scenarios across all impact categories except for FET. The impact derives from the electricity used to pump water from deep aquifers.

The fungicide tebuconazole and the herbicide glyphosate were two relevant chemical inputs affecting primarily Human Toxicity (HT and HT-C). They were also the main contributor to FET when present.

4. ACKNOWLEDGEMENTS

This research was funded by the Spanish Ministry of Economy and Competitiveness (MINECO) under Project AGL2014-52465-C4-1-R. It has been made possible thanks to collaboration with Inèdit Innovació.

5. REFERENCES

Brentrup F & Kusters J (2000). Methods to estimate potential N emissions related to crop production. Agric. data life cycle assessments. Wedeima, the Hague (Netherlands).

Chatzisymeon E, Foteinis S and Borthwick AGL (2016). Life cycle assessment of the environmental performance of conventional and organic methods of open field pepper cultivation system. Int. J Life Cycle Assess.

ISO, 2006a. ISO 14040. Environmental Management – Life Cycle Assessment – Principles and Framework. International Organization for Standardization.

ISO, 2006b. ISO 14044. Environmental Management – Life Cycle Assessment – Requirements and Guidelines. International Organization for Standardization.

EEA (2016). Agriculture and climate change. Available at http://www.eea.europa.eu/signals/signals-2015/articles/agriculture-and-climate-change. (Last accessed 03.05.17)

EMEP/EEA (2013). 3.B--Manure management In Air pollutant emission inventory guidebook 2016—technical report no 9/2009. European Environment Agency: Copenhagen.

EMEP/EEA (2016b). 3.D—Crop production and agricultural In Air pollutant emission inventory guidebook 2016—technical report no 9/2009. European Environment Agency: Copenhagen.

EPA, Environmental Protection agency (2016). Glyphosate issue paper: Evaluation of carcinogenic potential. EPA's office of pesticide programs.

Fantke P, Friedrich R, Jolliet O (2012*). Health impact and damage cost assessment of pesticides in Europe*. Environmental International Vol 49:9-17.

IPCC (Intergovernmental Panel on Climate Change) (2006a). In 2006 IPCC Guidelines for National Greenhouse Inventories. Vol.4: Agriculture, forestry and other land use, chapter 11: N2O emissions from managed soils, and co2 emissions from lime and urea. Prepared by the National Greenhouse Gas Inventories Programme. In: Eggleston HS, Buendia L, MiwaK, Ngara T, Tanabe K (eds) N2O Emissions from managed soils and CO2 emissions from lime and urea application. Published by the Institute for Global Environmental Strategies (IGES), Hayama.

Nemecek T, HA (2004). *Life Cycle Inventories of Agricultural Production Systems.* 518. *Final Report Ecoinvent 2000 No. 15.* Dübendorf, Suiza: Agroscope FAL Reckenholz and FAT 519 Taenikon, Swiss Centre for Life Cycle Inventories

Rouault A, Beauchet S, Renaud-Gentie C, Jourjon F (2016). Life cycle assessment of iticultural technical management routes (TMRs): comparison between an organic and an integrated management route. *Journal international des sciences de la vigne et du vin* 50:2:77-89.

Villanueva-Rey P, Vázquez-Rowe I, Moreira MT, Feijoo G (2014). Comparative life cycle assessment in the wine sector: biodynamic vs. conventional viticulture activities in NW Spain. *Journal of Cleaner Production* 65:330-341.

WHO, World Health Organization (2016). Pesticide residues in food? Online Q&A. Available at: http://www.who.int/features/qa/87/en/ Accessed June 18 2017.

UMN (c2017). Commercial fruit and vegetable production, University of Minnesota Extension. Available at: http://www.extension.umn.edu/garden/fruit-vegetable/using-manure-and-compost/ Last accessed (03.05.17).

Utilización de análisis de ciclo de vida para comparar los impactos medioambientales y las demandas de energía en un viñedo

Resumen: El estudio compara cinco métodos de gestión de viñedo. Los métodos varían entre intensivo (mecánico y químico), bajo insumo y dos métodos ecológicos. Usando la técnica de Análisis Ciclo de Vida (ACV), los impactos medioambientales de los sistemas han sido evaluados durante dos años. La principal unidad de comparación o unidad funcional es un kilogramo de uva. También se hace la comparación usando una hectárea de terreno para poder analizar cómo repercute la producción en los resultados finales y cuál es el «impacto bruto» al medio de cada sistema. Los resultados muestran que el fertilizante mineral es el insumo con más impacto. En los sistemas donde no aplican fertilizante mineral, la electricidad consumida por la bomba de riego genera el mayor impacto. De todos los procesos utilizados para manejar la mala hierba, la aplicación del herbicida glifosato resultó ser el más impactante. Los manejos intensivos produjeron el rendimiento más alto, pero también el mayor impacto medioambiental. Todo lo anterior con la excepción del sistema Ecológico 1 que ha tenido un rendimiento excepcionalmente alto, lo cual no suele pasar en sistemas de manejo ecológico.

Palabras clave: viticultura, ACV, malas hierbas, fitosanitario, fertilizante.