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GREENHOUSE GAS ASSESSMENT OF WINE PRODUCED IN PORTUGAL

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Abstract *This article presents a life-cycle (LC) greenhouse gas (GHG) assessment of wine produced in five wine regions of Portugal (Bairrada, Dão, Távora-Varosa, Douro e Vinho Verde). A cradle-to-gate approach was followed, including grape growing, grape transportation and winemaking. The GHG intensity of the entire LC of wine production can vary from 151 to 446 g* CO_2*eq per 0.75 L of wine (without wine packing and final transportation). The results showed that grape growing is the LC stage with the highest GHG emissions (between 88% and 92%). There is a significant variation of wine GHG intensity among the various producers, but not for the different types of wine in each producer.*

1. INTRODUCTION

Portugal produced 624 million litters and exported 227 million litters in 2013 [1]. The environmental life-cycle impacts of wine production have been explored in previous studies (e.g. [2, 3, 4]); however, in Portugal just for the wine region of "Vinho Verde" (northern of Portugal) [5]. Rugani et al [6] presented a literature review of the carbon footprint of wine and concluded that the GHG emissions of: (i) grape growing ranged from 45 to 2000 g CO_2eq (average of 380 g CO_2eq) per 0.75 L of wine and (ii) winemaking from 3 to 1900 g CO_2eq (average of 260 g CO_2eq) per 0.75 L of wine. This article presents a life-cycle (LC) greenhouse gas (GHG) assessment of wine produced in five wine regions of Portugal (Bairrada, Dão, Távora-Varosa, Douro e Vinho Verde).

2. LIFE-CYCLE MODEL AND INVENTORY

The LC model for wine produced in Portugal included grape growing (viticulture), grape transportation and wine production, but did not include packaging and final transportation. The functional unit (FU) chosen was 0.75 L of wine. Four types of wine (red, rosé, white and sparkling) produced in five wine regions (Bairrada, Dão, Távora-Varosa, Douro and Vinho Verde) were considered. The GHG emissions associated with agricultural inputs production (pesticides, fertilizers, and diesel) and transportation were considered based on [7, 8, 9, 10]. Direct and indirect N_2O field emissions were calculated using the IPCC Tier 1 methodology [11]. Global warming potentials for a 100-year time horizon were adopted from [11].

Table 1 presents the main inputs, productivity and grape transportation distances for 11 grape growing systems, in various recent years. Grape growing includes soil cover management, fertilization, sowing, pest control, and harvesting. Wine is usually produced close to vineyards (the grapes being transported at most 50 km). Eleven grape producers were considered: eight small producers from regions *B (BA, BB, BC, BD)*, *D* (*DA*, *DB*) and *C* (*CA*, *CB*) and three large producers from the regions *E* (*EA*, *EB*) and *F (FA)*. The productivity varies from 2.9 to 8.3 t of grapes per ha.

Table 2 shows the main inputs of three wine producers (*W_b*, *W_d*, *W_c*) from three regions (*B*, *D* and *C*). It was assumed that bagasse and stalk corresponds respectively to 13.5% and 4% of the total mass of processed grapes [12], since there was no information available. It was also considered that stalk was applied in the agricultural field. Bagasse was sold (0.06 € kg^{-1} of bagasse), but it represents a very low cash flow (less than 1% of the wine cashflow) and no allocation of GHG emissions was performed (100% of emissions to wine).

Table 1. Main inputs and productivity (per ha): grape growing and transportation.

	Region	*B*				*D*		*C*	
	Producer	*BA*	*BB*	*BC*	*BD*	*DA*	*DB*	*CA*	*CB*
	Area	*17ha*	*3ha*	*6ha*	*6ha*	*2.5ha*	*6ha*	*14ha*	*7ha*
	Year	2011 and 2012	2012	2012	2012	2012	2012	2012	2011
Chemical Fertilizers	N (kg)	17.5	72	-	18	-	-	13	46
	P (kg)	35	48	-	16	-	-	26	83
	K (kg)	35	48	-	20	-	-	27	83
	Calcium Nitrate (kg)	6.8	-	-	-	-	-	-	-
	$CaCO_3$ (kg)	280	-	-	-	-	144	-	140
	Boron (g)	-	100	-	40	400	300	200	220
	Magnesium (kg)		-	-	-	6	-	-	-
	Magnesium oxide (kg)	-	-	-	-	-	12.6	-	-
Organic Fertilizers	N (kg)	-	-	-	4.3	-	-	-	-
	Poultry manure (kg)	-	-	-	-	400	9418	-	-
Pesticides (a.i.)	Azoxystrobin (kg)	9	-	0.2	-	-	0.13	1.5	-
	Glyphosate (kg)	1.44	-	2.34	1.2	-	1.35	-	-
	Folpet (kg)	0.95	2.23	1.5	1.24	0.6	-	-	1
	Metalaxyl-M (g)	50	100	50	-	170	-	-	-
	Mandipropamid (g)	60	-	60	-	-	-	-	-
	Copper oxide (g)	440	-	480	-	-	-	-	-
	Mancozeb (kg)	-	-	-	0.22	0.6	2.7	0.98	-
	Fosetyl-Al (kg)	-	1.5	-	0.53	0.45	-	0.98	2.1
	Sulfur (kg)	-	-	-	-	2.5	13.6	78	-
	Trifloxystrobin (g)	-	80	-	-	-	-	-	-
	Tebuconazole (g)	-	8	-	40	-	-	-	-
	Cymoxanil (g)	-	100	-	200	-	290	-	-
	Copper (kg)	-	1.9	-	1.5	-	-	-	0.74
	Fungicide unspecified (kg)	-	1	-	-	-	-	-	-
	Pesticide unspecified (g)	-	-		-	-	450	-	-
	Penconazole (g)	-	-	40	30	30	-	-	-
	Glufosinate (g)	-	-	-	430	-	-	-	-
	Chlorpyrifos (g)	-	-	-	240	-	-	-	-
	Spiroxamin (g)	-	-	-	170	-	-	-	-
	Metiram (kg)	-	-	-	1.56	-	-	-	-
	Fenhexamid (g)	-	-	-	410	-	-	-	-
	Methoxyfenozide (g)	-	-	-	80	-	-	-	-
	Copper oxychloride (g)	-	-	-	-	400	570	-	-
	Tetraconazol (kg)	-	-	-	-	-	-	-	1.26
Diesel (L)		176[a]	475	580	333[a]	194	270	200[a]	139[a]
Grape transportation (km)		6	10	6	50	1	12	1	12
Productivity (t)		5.85 6.50	6.00	8.30	4.12	3.20	6.83	6.79	6.94

[a)]- Diesel for transportation is included in total diesel consumption.

Table 1. (continued).

	Region	*E*						*F*	
	Producer	*EA*			*EB*			*FA*	
	Area	*87ha*			*168ha*	*193ha*		*65ha*	
	Year	2010	2011	2012	2010	2011	2012	2010	2011
Chemical Fertilizers	N (kg)	0.15	0.06	0.03	-	-	-	2.5	-
	P (kg)	61.9	22.4	13.4	0.27	0.24	-	20	18
	K (kg)	63.6	21.5		0.54	1.25	0.78	10.3	12.9
	Fito algae (kg)	-	-	-	-	1.81	1.81	-	-
	CaCO3 (kg)	28.9	160.9	-	-	-	-	44.1	-
	$CaMg(CO_3)_2$ (kg)	305.7	225.3	679.9	-	-	-	-	-
	Boron (g)	-	-	-	45	39	-	-	-
	Magnesium oxide (g)	-	-	-	-	194	194	-	-
Organic Fertilizers	N (kg)	15.6	-	8.8	-	-	-	18.6	25.8
	P (kg)	6.4	-	4.4	-	-	-	8.3	12.9
	K (kg)	6.4	-	4.4	-	-	-	-	-
Pesticides (a.i.)	Oxiflurone (g)	-	-	-	743	373	249	-	-
	Glyphosate (kg)	1.57	1.07	1.16	1.07	1.84	1.83	-	-
	Flazasulfuron (g)	-	-	-	2.97	15.5	7.77	-	-
	Kresoxim-Methyl (g)	-	2.29	34.5	42.8	72.5	15.5	-	-
	Copper hydroxide (g)	-	-	-	833	635	544	-	-
	Cyazofamid (g)	-	-	-	77.4	-	13	-	-
	Fluopicolide	-	-	-	91.7	20.5	34.2	-	-
	Fosetyl-Al (g)	-	69	-	1388	311	-	2262	-
	Spiroxamine (g)	-	-	-	232	453	259	-	-
	Proquinazida (g)	-	-	-	31	-	-	-	-
	Tebuconazole (g)	121	86.2	-	77.4	-	-	145	85.1
	Sulfur (kg)	2.76	5.06	6.21	22.6	24.6	12.3	9.85	19.7
	Flufenoxuron (kg)	-	-	-	11.3	-	-	-	-
	Quizalope-P-ethyl (g)	-	0.58	-	-	9.1	11.7	-	-
	Diflufenican (g)	-		-	-	16.6	15.5	-	-
	Folpet (kg)	1.17	1.48	1.06	-	1.43	-	0.09	2.71
	Metalaxyl-M (g)	293	172	264	-	77.8	64.8	400	400
	Cimoxanyl (g)	27.6	46	22.1	-	49.7	60.1	125	111
	Copper oxychloride (kg)	-	-	-	-	1.27	1.17	0.86	-
	Metiram (g)	-	-	-	-	185	171	-	-
	Pyraclostrobin (g)	-	-	-	-	16.8	15.5	-	-
	Iprovalicarb (g)	-	114	-	-	88.6	88.6	-	-
	Chlorantraniliprole (g)	-	-	-	-	6.2	12.4	-	-
	Metoxifenocida (g)	-	-	-	-	14.9	14.9	-	-
	Trifloxystrobin (g)	-	-	-	-	-	-	154	-
	Mancozeb (kg)	0.321	0.534	0.257	-	-	-	2.26	-
	Amonium glufosinate (g)	379	371	344	-	-	-	185	92.3
	Terbuthylazine (g)	919	-	-	-	-	-	-	-
	Myclobutanil (g)	17.1	-	-	-	-	-	-	0,3
	Quinoxyfen (g)	17.1	25.9	230	-	-	-	-	-
	Meptyldinocap (g)	-	129	133	-	-	-	-	-
	Boscalid (g)	-	4.60	69.0	-	-	-	-	-
	Dimethomorph (g)	-	8.31	-	-	-	-	-	-
	Chlorantraniliprole (g)	-	4.60	-	-	-	-	-	-
	Cyprodinil (g)	-	-	51.7	-	-	-	-	-
	Fludioxonil (g)	-	-	17.2	-	-	-	-	-
	Metrafenone (g)	-	-	34.5	-	-	-	-	-
	Glufosinate (g)	-	59.7	-	-	-	-	-	-
	Thiophanate methyl (kg)	-	-	2,1	-	-	-	-	-
Water (L)		4138	4138	4713	-	-	-	-	-
Diesel (include diesel for grape transportation) (L)		75.6	124.7	132.2	88.9	96.2	92.5	184.6	215.4
Petrol (L)		-	-	-	-	-	-	1.54	1.54
Productivity (t)		2.89	3.51	2.55	4.35	3.50	4.35	5.38	5.77

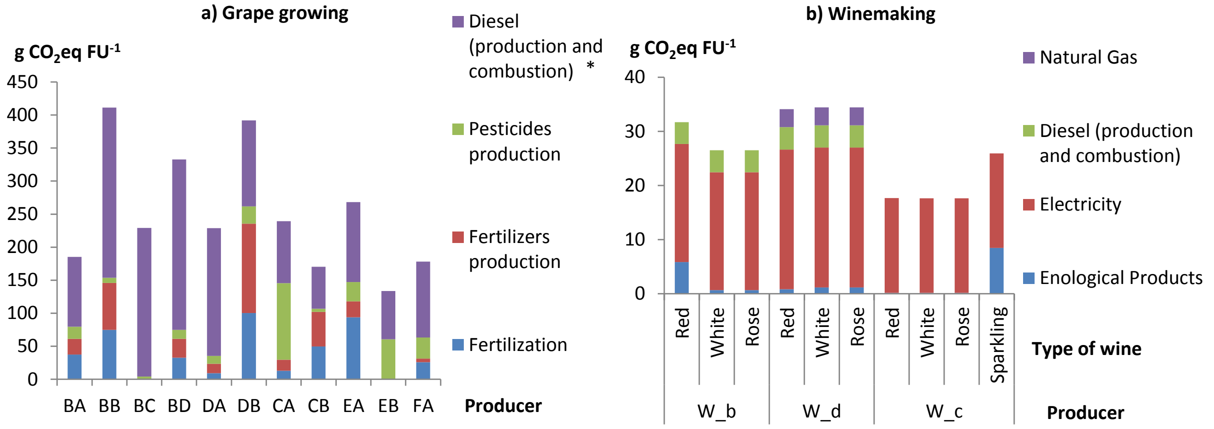
Table 2. Wine production in three wine regions in Portugal: main inputs and outputs (per 0.75L of wine).

Inputs / Producer	*W_b*			*W_d*			*W_c*				Units
	Red	White	Rose	Red	White	Rose	Red	White	Rose	Sparkling	
Enological Products											
Sulfur dioxide	67.5	67.5	67.5	97.8	97.8	97.8	56.3	56.3	56.3	56.3	mg
Sugar	3	-	-	-	-	-	-	-	-	-	g
Yeast	225	225	7.5	130	130	130	-	10	10	9000	mg
Ascorbic acid[a]	37.5	45	45	-	50	49.8	-	-	-	-	mg
Sorbate[a]	37.5	113	113	-	-	-	-	-	-	-	mg
Filtrostabil (Arabic gum)[a]	0.75	-	-	-	-	-	-	-	-	-	mg
Citric acid[a]	-	75	75	-	-	-	-	-	-	-	mg
CMC [stabilizer]	-	1.5	1.5	-	-	-	-	-	-	-	mg
Nutrients	-	-	-	326	326	326	-	-	-	-	mg
Tannins[a]	-	-	-	52.2	52.2	52.2	-	-	-	-	mg
Enzymes[a]	-	-	-	7.83	7.83	7.83	-	-	-	-	mg
Gelatins[a]	-	-	-	-	750	750	-	75	75	75	mg
Bentonite	-	-	-	-	-	-	188	169	169	169	mg
Albumin[a]	-	-	-	-	-	-	93.8	-	-	-	mg
Metatartaric acid[a]	97.9	-	-	-	-	-	-	-	-	-	g
Tartaric acid[a]	-	-	-	163	163	163	-	-	-	-	mg
Energy											
Electricity	47	47	47	56	56	56	38	38	38	38	Wh
Diesel	1.3	1.3	1.3	1.3	1.3	1.3	-	-	-	-	mL
Natural Gas	-	-	-	49	49	49	-	-	-	-	J
Water	1.75	1.75	1.75	0.98	0.98	0.98	0.08	0.08	0.08	0.08	L
Grapes	1	1	1	1	1	1	1	1	1	1	kg
Outputs											
Wine	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	L
Stalk	26	26	26	26	26	26	26	26	26	26	g
Bagasse	0.11	0.11	0.11	0.11	0.11	0.11	0.23	0.23	0.23	0.23	kg

[a]- Production not available in Ecoinvent database

3. RESULTS AND DISCUSSION

Figure 1 shows the GHG intensity per life-cycle stage (and 0.75 L of wine) for each producer. Grape growing was the life-cycle phase that most contributed to the GHG emissions (between 86% and 92%). The GHG emissions in this phase ranged from 134 g CO_2eq (*EB*) to 411 g CO_2eq (*BB)* per 0.75 L of wine. This difference was due to lower energy and fertilizer use by *EB* compared to *BB*. For *CA* and *EB* grape producers, the main contributors to the GHG emissions were diesel (39% and 55%, respectively for *CA* and *EB*) and pesticides (48% and 45%). For the remaining producers, fertilizers and diesel were the main contributors to GHG emissions (together representing between 82% and 99%). The GHG emissions associated with winemaking ranged between 18 and 35 g CO_2eq per 0.75 L (mainly related with energy requirements). For W_b, GHG emissions are higher for Red wine (due to sugar use); while for W_c is Sparkling wine (due to yeast).



*Include agricultural operations and transportation

Figure 1. GHG intensity (per FU=0.75L) of: a) Grape growing; b) Winemaking.

4. CONCLUSIONS

The life-cycle GHG assessment of wine produced in five wine regions of Portugal was presented. The total wine GHG intensity varies between 151 g CO_2eq and 446 g CO_2eq per 0.75 L of wine. The range of GHG emissions reported are lower than those reported in the literature for other countries. Grape growing is the LC phase with the highest GHG emissions (88% to 92%). There is a significant variation of the GHG intensity of the wine for the various producers, but not for the different types of wine. Efforts to reduce GHG emissions should be focus on the cultivation, including the adoption of best agricultural management practices, according to soil analysis, land morphology and weather conditions. In addition, due to the high variation of the results, an uncertainty analysis should be included in the future.

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