LCA of sunflower oil addressing alternative land use change scenarios and practices

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ABSTRACT

Sunflower oil is one of the leading food oils, recently also used for biodiesel production, mainly in southern European countries. This paper presents a Life-Cycle Assessment of sunflower oil produced in Portugal. Two alternative agriculture practices (irrigated and non-irrigated cultivation) were assessed. Twenty-eight alternative land use change (LUC) scenarios were studied (combining four actual land use types and seven scenarios for the reference land use). Life-cycle Impact Assessment results were calculated (ReCiPe method) for six impact categories. Sunflower cultivated on non-irrigated land had higher environmental impacts in 4 categories because of the low productivity, while sunflower cultivated in irrigated land had higher impacts in only 2 categories (due to the use of fertilisers). Cultivation is the main contributor to the life-cycle impacts in all categories. A huge variation in greenhouse gas intensity for sunflower oil was calculated (0.3-20.9 kg CO_{2eq}/kg_{oil}). The results show the importance of LUC and cultivation practices in the environmental performance of sunflower oil.

Keywords: agriculture practices, greenhouse gas, irrigation, land use change (LUC), sunflower oil

1. Introduction

Sunflower is one of the leading oilseed crops used for the production of oil for human consumption. It has also been considered an important crop for biodiesel production in southern European countries (Kallivrossis, 2002). Life-cycle Assessment (LCA) was employed to assess sunflower oil; most of the studies were in the scope of biodiesel production (JEC, 2008, Kallivrossis, 2002, Requena et al., 2010, Tsoutsos et al., 2010). Other LCA studies focused on sunflower cultivation (Cotana et al., 2010) and the use of sunflower oil in agricultural tractors on Greek farms (Balafoutis et al., 2010). However, only one of these LCA studies (Iriarte et al., 2010) addressed land use change (LUC).

LUC is an emergent topic with important implications in terms of the greenhouse gas (GHG) balance of food and bioenergy crops, as demonstrated by several LCA studies for vegetable oils and oil-based biodiesel systems, which have concluded that the GHG intensity is sensitive to the type of LUC. For example, Castanheira and Freire (2011a;b) evaluated LUC for soybean produced in Latin America and palm oil produced in Colombia, calculating a large variation in GHG intensity between different LUC scenarios. Lechon et al., (2011) studied alternative biofuel feedstocks (soybean, palm, rapeseed, sunflower oil), concluding that when LUC impacts are considered the benefits of biofuels are significantly reduced and can even be negative. Malça and Freire (2011) assessed the implications of LUC for bioethanol produced from wheat, and Malça and Freire (2010) assessed rapeseed oil, both produced in Europe, concluding that GHG emissions due to LUC dominate results and have high uncertainty.

Increasing prices of food products together with the expansion of biodiesel produced from vegetable oils in Europe may lead to an increase in the production of sunflower in Portugal, which can be achieved by the expansion of sunflower plantation area (extensification) or by an increase in the productivity (intensification). This motivates assessing the environmental impacts of sunflower oil produced in Portugal, including the carbon-stock changes caused by alternative LUC scenarios. The main objective of this paper is to present an LCA of sunflower oil produced in Portugal.

2. Life-Cycle Model and Inventory

A life-cycle model and inventory for sunflower oil produced in Portugal were developed and implemented. The life-cycle model includes the land use conversion necessary to establish sunflower cultivation, cultivation, transportation, oil extraction and treatment (Fig. 1). For sunflower cultivation, two systems were considered: irrigated and non-irrigated. The infrastructure for facilities, machines and vehicles was included (even that not presented in Fig. 1). The functional unit chosen was 1 kg of oil. The oil chain is multifunctional, with one co-product (sunflower meal). According to ISO 14044 (2006), whenever several allocation approaches seem applicable, a sensitivity analysis shall be conducted to illustrate how different methods change the results. In this study, three allocation methods were analysed: mass, energy and economic.

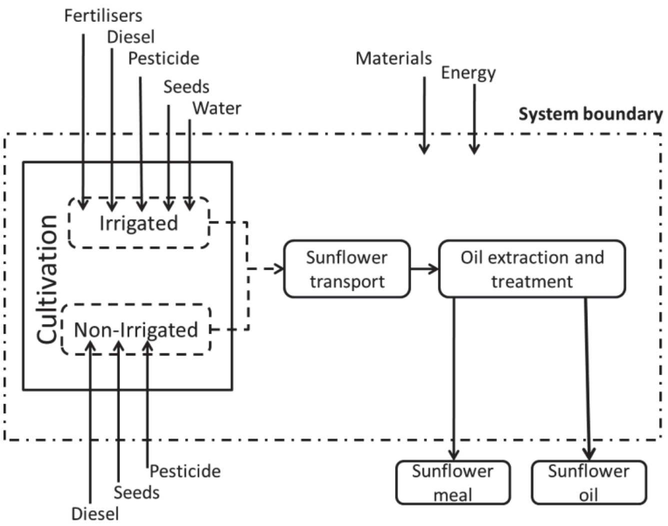

Figure 1. Sunflower oil chain: main processes and system boundaries.

Table 1 shows the main inventory data (average) for sunflower cultivation (a); oil extraction and treatment (b). Two alternative agriculture practices (irrigated and non-irrigated cultivation) were modelled. The main difference between these practices is that irrigated cultivation requires 3000-6000 m^3/ha/year of water (Toureiro et al., 2005) and fertilisers (Table 1), while non-irrigated cultivation does not use either. The average productivity of irrigated cultivation is 3000 kg/ha/year, while non-irrigated cultivation is 650 kg/ha/year (Gírio et al., 2010). Data for the oil extraction process, using hexane as a solvent, was based on Jungbluth et al., (2007). After extraction, the oil was separated from the solvent by a distillation process.

Table 1. Main inventory data: a) sunflower cultivation (1 kg sunflower); b) extraction and treatment of sunflower oil (1 kg, no allocation).

a)

Main Inputs		Irrigated	Non-Irrigated	Unit
Fertilisers	N	0.007	-	kg
	K_2O	0.021	-	kg
	P_2O_5	0.021	-	kg
Pesticide (atrazine)		0.001	0.0023	kg
Seeds for planting		0.0023	0.0046	kg
Diesel		0.0523	0.1539	L
Water		1.5	_-	m^3
Product		**Irrigated**	**Non-Irrigated**	**Unit**
Sunflower seeds		1	1	kg

b)

Main Inputs	Value	Unit
Sunflower seeds	2.29	kg
Natural Gas	1.63	MJ
Bentonite	5.38×10^{-3}	kg
Hexane	2.53×10^{-3}	kg
Phosphoric acid	8.16×10^{-4}	kg
Electricity	9.66×10^{-2}	kWh
Co-products	**Value**	**Unit**
Sunflower oil	1	kg
Sunflower meal	1.29	kg

3. Land use change scenarios and carbon calculations

Twenty-eight LUC scenarios were assessed based on a combination of seven reference land use types (grassland (R1-R3) and perennial crops (R4-R7)) and four actual land uses (irrigated sunflower (I) (A1 and A2) and non-irrigated sunflower (NI) (A3 and A4)) (Table 2). The emissions from carbon-stock changes caused by LUC (e_1, kg CO_{2eq}/kg_{oil}) were calculated using IPCC Tier 1, (IPCC, 2006) and adapting the following equation from the Renewable Energy Directive (RED, EC, 2009):

$$e_1 = (C_{SR}-C_{SA}) \times 3.664 \times 1/20 \times 1/P \qquad \text{Eq. 1}$$

in which:
C_{SR} is the carbon stock associated with the each reference LU (kg CO_{2eq}/ha);
C_{SA} is the carbon stock associated with the actual LU (sunflower oil plantation) (kg CO_{2eq}/ha);
P is the sunflower oil productivity (kg oil/ha)

Based on the Portuguese climate region (warm temperate dry) and soil type (high activity clay soils), a standard value of 38 t C/ha was obtained from EC (2010) for soil organic carbon (SOC_{ST}). To calculate the reference and actual land use soil organic carbon (SOC_R and SOC_A), appropriate values for the factors reflecting the difference in SOC associated with type of land use (F_{LU}), management practice (F_{MG}) and different levels of carbon input to soil (F_I) compared to the SOC_{ST} were selected from EC (2010) (Table 2). Above and below-ground vegetation carbon stock (C_{VEG}) also came from EC (2010) (Table 2).

Table 2. Calculated soil organic carbon (SOC), above and below-ground vegetation carbon stock in living biomass (C_{VEG}), and total values (C_S) for reference ($_R$ subscript) and actual ($_A$ subscript) land use.

Actual Land Use		SOC_i =(SOC_{ST}*F_{LU}*F_{MG}*F_I)				SOC_i (t C/ha)	C_{VEGi} (t C/ha)	$CS_i = SOC_i + C_{VEGi}$ (t C/ha)
		SOC_{ST} (t C/ha)	F_{LU}	F_{MG}	F_I			
Sunflower cultivation (irrigated, RT, medium input)	A1	38	0.8	1.02	1.00	31.01	0	31.01
Sunflower cultivation (irrigated, NT, medium input)	A2	38	0.8	1.10	1.00	33.44	0	33.44
Sunflower cultivation (non-irrigated, RT, low input)	A3	38	0.8	1.02	0.95	29.46	0	29.46
Sunflower cultivation (non-irrigated, NT, low input)	A4	38	0.8	1.10	0.95	31.77	0	31.77
Reference Land Use								
Grassland (improved, medium input)	R1	38	1.0	1.14	1.00	43.32	3.1	46.42
Grassland (improved, high input)	R2	38	1.0	1.14	1.11	48.09	3.1	51.19
Grassland (severely degraded, medium input)	R3	38	1.0	0.70	1.00	26.60	3.1	29.70
Perennial crop (RT, high input, with manure)	R4	38	1.0	1.02	1.37	53.10	43.2	96.30
Perennial crop (RT, high input, without manure)	R5	38	1.0	1.02	1.04	40.31	43.2	83.50
Perennial crop (NT, high input, with manure)	R6	38	1.0	1.10	1.37	57.27	43.2	100.40
Perennial crop (NT, high input, without manure)	R7	38	1.0	1.10	1.04	43.47	43.2	86.67

NT: no tillage; RT: reduced tillage; F_{LU}: type of land use; F_{MG}: management practice; F_I: different levels of carbon input to soil.

4. Results and Discussion

Life-cycle Impact Assessment (LCIA) results were calculated using the ReCiPe method (midpoint level and hierarchical perspective; Goedkoop et al., 2010). We selected the following six impact categories: climate change (CC), ozone depletion (OD), terrestrial acidification (TA), freshwater eutrophication (FWE), marine eutrophication (ME) and fossil depletion (FD). The allocation method had an important influence in the results. In this study, three allocation methods were analysed: mass (43% oil, 57% meal), energy (65% oil, 35% meal) and economic (77% oil, 23% meal). The highest impacts occurred for economic allocation. Below we present only results for mass-based allocation.

4.1. LCIA results excluding LUC

Sunflower cultivated on non-irrigated land had higher environmental impacts in the categories of CC, ME, FD and OD because of the low productivity per ha (650 kg/ha/year) (Table 3). On the other hand, sunflower cultivated on irrigated land (3000 kg/ha/year) had higher impacts for TA and FWE, due to the use of fertilisers. The life-cycle phase of sunflower oil with the highest environmental impacts was cultivation for all categories (70%-99%). The main contributors for the impacts in sunflower cultivated on irrigated land were fertilisers (10%-99%, for all impact categories) and diesel for agricultural processes (30%-45%, for all categories except FWE). The main contributor in non-irrigated cultivation was diesel (64%-84%, for all categories).

Table 3. LCIA results (1 kg sunflower oil, mass allocation, no land use change).

	CC (kg $CO_{2\,eq}$) x10^{-1}		OD (kg CFC^{-11}) x10^{-7}		TA (kg $SO_{2\,eq}$) x10^{-3}		FWE (kgP $_{eq}$) x10^{-4}		ME (kg N $_{eq}$) x10^{-3}		FD (kg oil $_{eq}$) x10^{-1}	
	I	NI	I	NI	I	NI	I	NI	I	NI	I	NI
Cultivation	6.08	8.22	0.72	1.05	4.34	3.94	3.56	0.085	1.42	2.12	1.87	2.53
Oil Extraction	0.81		0.10		0.28		0.025		0.047		0.32	
Total	6.89	9.03	0.82	1.15	4.62	4.22	3.59	0.11	1.47	2.17	2.19	2.85

I – Irrigated; NI – Non-Irrigated; CC – Climate change; OD – Ozone layer depletion; TA – Terrestrial acidification; FWE – Freshwater eutrophication; ME – Marine eutrophication; FD – Fossil depletion.

Normalised results (using global values for the Europe Union (EU_{25+3}) year 2000, as reference) were calculated. Normalisation is an optional step in LCA and relates the magnitude of the impacts to reference values (Clift et al., 2000). It places LCIA indicator results into a broader context and adjust the results to have common dimensions. Fig. 2 shows that normalised results had similar magnitude for all categories (0.6 x10^{-4} - 1.7 x10^{-4}), except for FWE and OD. FWE had the highest normalised impacts for irrigated cultivation due to the use of P_2O_5 fertiliser (Fig. 2). These impacts are about 30 times higher than those for non-irrigated cultivation (in which there was no fertiliser input), meaning that the use of fertiliser dominates the impacts in FWE.

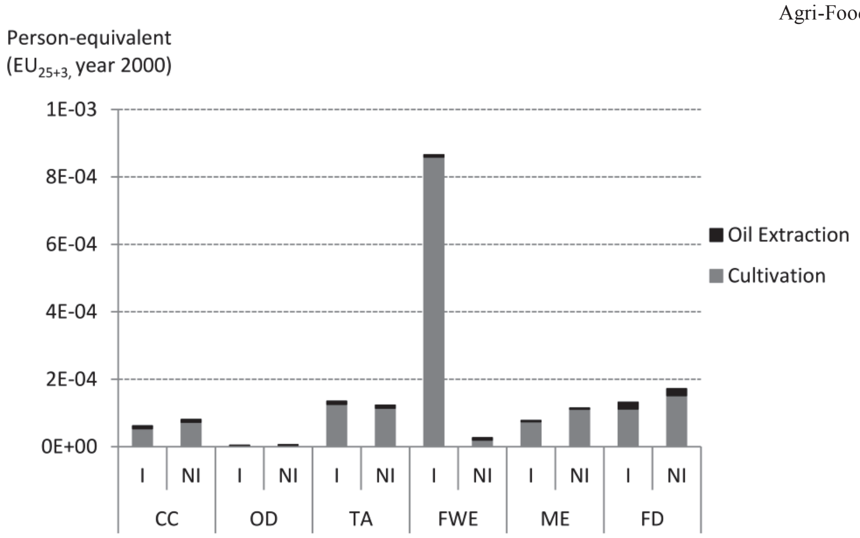

Figure 2. Normalised LCIA results (1 kg sunflower oil, mass allocation, no land use change).

4.2. Climate change impact: LUC scenario analysis

Sunflower oil GHG intensity greatly depends on the LUC scenario and varies greatly (0.3-20.9 kg CO_{2eq}/kg_{oil}) (Fig. 3). The lowest values were obtained when sunflower was cultivated on severely degraded grassland (R3), for which there was an increase in SOC (negative GHG emission in Fig.3). Highest values occurred when perennial crops (R4 to R7) were converted into sunflower cultivation, due to an important loss of above and below-ground vegetation carbon stock (C_{VEG}) from the previous perennial crop land.

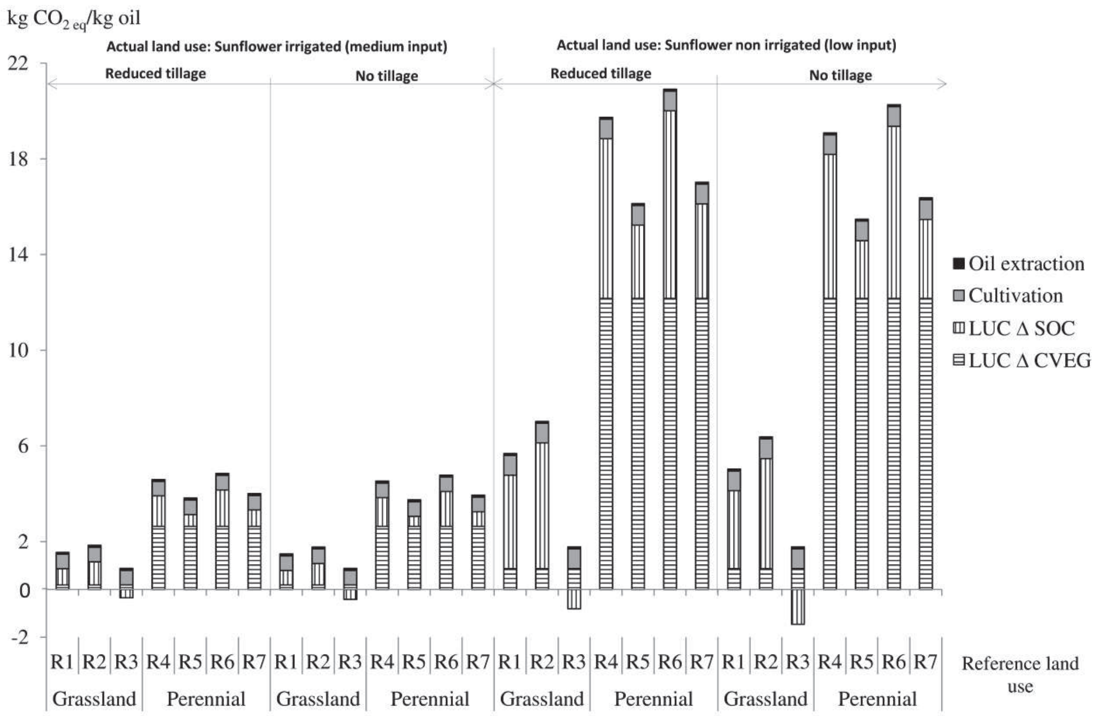

Figure 3. Greenhouse gas intensity of sunflower oil: land use change (LUC) and agriculture-practice scenarios (mass allocation).

5. Conclusion

Sunflower cultivated on non-irrigated land had higher environmental impacts in 4 categories (CC, ME, FD and OD) because of the low productivity per ha (650 kg/ha/year), while sunflower cultivated in irrigated land (3000 kg/ha/year)) had higher impacts in only 2 categories (TA and FWE) due to the use of fertilisers. The FWE impacts were about 30 times higher for irrigated cultivation relatively to non-irrigated cultivation (in which there was no fertiliser input). Cultivation contributed 70%-99% to the life-cycle impacts in all categories, mainly due to fertilisers and diesel (agricultural processes in irrigated cultivation). Normalised results had similar magnitude for all categories, except for FWE and OD.

A huge variation in GHG intensity for sunflower oil in Portugal was calculated (0.3-20.9 kg CO_{2eq}/kg_{oil}, mass allocation), demonstrating that agricultural practices and LUC scenarios have an important influence on GHG intensity. To assure low GHG intensity, sunflower should preferably be cultivated in severely degraded grassland. Cultivation on previous perennial crop land should not be used.

6. Acknowledgment

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