Energy for Sustainability 2013
Sustainable Cities: Designing for People and the Planet
Coimbra, 8 to 10 September 2013

LIFE-CYCLE ASSESSMENT OF SUNFLOWER ADDRESSING LAND USE CHANGE

Filipa Figueiredo[1]*, Érica Castanheira[1] and Fausto Freire[1]

1: ADAI-LAETA (Center for Industrial Ecology)
Department of Mechanical Engineering, University of Coimbra
Rua Luís Reis Santos, 3030-788 Coimbra, Portugal
*e-mail: filipa.figueiredo@dem.uc.pt, erica@dem.uc.pt, fausto.freire@dem.uc.pt, web: http://www2.dem.uc.pt/CenterIndustrialEcology/

Keywords: Environmental impacts; Greenhouse gas; Irrigated sunflower; Life-cycle assessment; Rainfed sunflower.

Abstract *Recent life-cycle assessment (LCA) studies of sunflower oil and biodiesel, identified the agricultural phase has the main contributor to environmental impacts. This article presents a Life-Cycle Assessment of sunflower seeds produced in Portugal. Two agriculture practices (irrigated and rainfed), combined with alternative land-use change (LUC) scenarios (conversion of severely degraded grassland and perennial cropland, with and without manure application) were analysed. The ReCiPe method was adopted for the life-cycle impact assessment and the following categories were analysed: climate change (CC), terrestrial acidification (TA), marine eutrophication (ME) and freshwater eutrophication (FWE). The results show that irrigated sunflower had lower impacts in CC and ME, mainly due to the high productivity. Rainfed sunflower had lower results for TA and FEW, due to not using fertilizers. The results show the importance of LUC and cultivation practices in the environmental performance of sunflower seeds.*

1. INTRODUCTION

Recent life-cycle assessment (LCA) studies of sunflower oil and biodiesel production have shown that the agricultural phase has an important contribution to the total environmental impacts (e.g. [1, 2]). The potential increase in sunflower production as a response to European policies in the framework of biodiesel [3] and a rising demand in food products motivate a comprehensive assessment of the cultivation of sunflower. The main objective of this paper is to present a LCA of sunflower seeds produced in Portugal, comparing two agriculture practices (irrigated and rainfed) and addressing the carbon-stock changes caused by alternative land-use change (LUC) scenarios.

2. LIFE-CYCLE MODEL AND INVENTORY

A life-cycle (LC) model for irrigated and rainfed sunflower in Portugal was implemented (Fig. 1). The model included the land use conversion necessary to establish sunflower cultivation, as well as the infrastructure for facilities, machines and vehicles. The functional unit selected for this study was 1 kg of sunflower seeds. Irrigated sunflower has a yield of 3000 kg ha^{-1} and the main inputs are fertilizers (ammonium nitrate: 21 kg ha^{-1}, triple superphosphate: 21 kg ha^{-1} and potassium sulphate: 63 kg ha^{-1}), water (4500 L ha^{-1}), pesticides (atrazine: 3 kg ha^{-1}), seeds (7 kg ha^{-1}) and diesel for agricultural operations (157 L ha^{-1}). Rainfed sunflower has a lower yield, 650 kg ha^{-1}, and the main inputs are atrazine (1.5 kg ha^{-1}), seeds (3 kg ha^{-1}) and diesel (100 L ha^{-1}) [4].

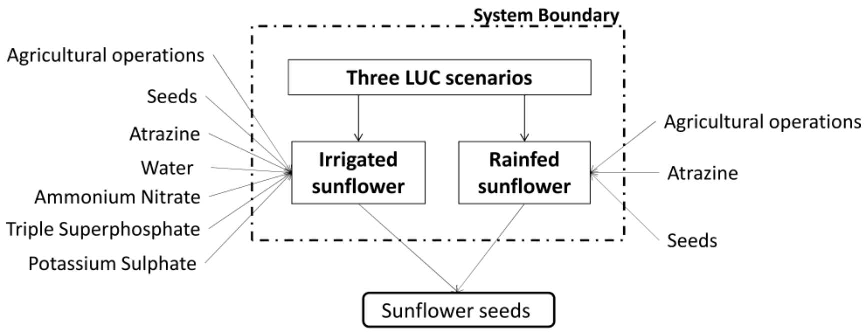


Figure 1. Sunflower oil chain: main processes and system boundaries.

Emissions of irrigated and rainfed sunflower included the emissions from carbon-stock changes caused by LUC, fertilization (nitrogen and phosphorus field emissions), diesel combustion in agricultural operations [5] and agricultural inputs production [5, 6, 7]. Regarding fertilization, the follow nitrogen emissions were considered: i) direct and indirect nitrous oxide (N_2O) emissions to air [8], ii) ammonia (NH_3) volatilization to air [8], iii) nitrate (NO_3^-) leaching/runoff to water [8], iv) nitrogen oxides (NO_x) emissions to air [9]. Emissions from leaching and run-off of soluble phosphate (PO_4) and erosion of soil particles containing phosphorus (P) were calculated based on SALCA-P model [10]. Table 1 presents nitrogen and phosphorus field emissions calculated for irrigated and rainfed sunflower (N_2O and NO_3^- emissions are presented as ranges inside brackets because these emissions vary for the various LUC scenarios).

Emissions	Irrigated	Rainfed
N_2O [g N_2O kg_{seeds}^{-1}]	[0.15, 1]	[0, 3.9]
NO_3^- [g NO_3^- kg_{seeds}^{-1}]	[9, 70]	[0, 287]
NH_3 [g NH_3 kg_{seeds}^{-1}]	0.81	0
NO_x [g NO_x kg_{seeds}^{-1}]	0.035	0
P[g P]	0.00069	0.0032
PO_4[g PO_4]	0.82	0.38

Table 1. Nitrogen and phosphorus field emissions from sunflower cultivation.

Emissions from carbon-stock changes caused by LUC (e_1, $kgCO_2eq\ kg_{seeds}^{-1}$) were calculated using IPCC Tier 1 methodology [8] and adapting the equation presented in the Renewable Energy Directive [3]. Emissions from LUC were calculated for six LUC scenarios, established based on a combination of alternative reference land uses (severely degraded grassland and perennial cropland, with and without manure application) and the two actual land uses (irrigated and rainfed sunflower). Table 2 shows the emissions from carbon-stock changes caused by the conversion of grassland and perennial crop to irrigated and rainfed sunflower.

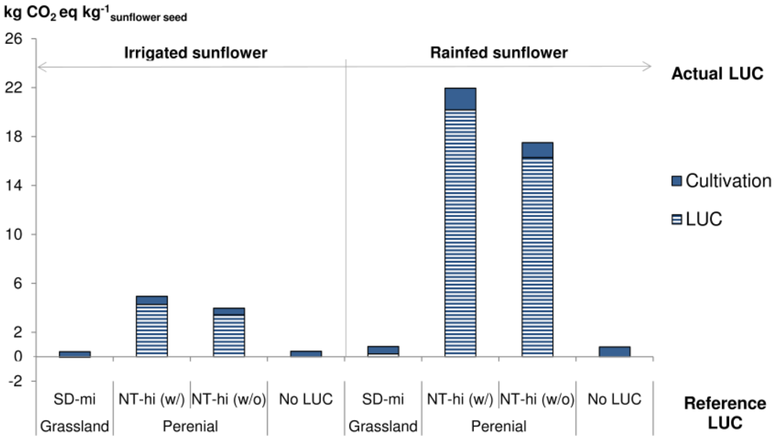
Reference land use	Actual land use	e_1 ($kgCO_2eq\ kg_{seeds}^{-1}$)
Grassland (SD-mi)		-0.04
Perenial (NT-hi (w/))	Irrigated sunflower	4.3
Perenial (NT-hi (w/o))		3.4
Grassland (SD-mi)		0.2
Perenial (NT-hi (w/))	Rainfed sunflower	20.2
Perenial (NT-hi (w/o))		16.3

SD: severely degraded; mi: medium input; NT: no-tillage; hi: high input;w/: with manure; w/o: without manure.

Table 2. Carbon-stock changes caused by LUC.

3. RESULTS AND DISCUSSION

Figure 2 presents the sunflower GHG intensity for 6 LUC scenarios and for no-LUC. The results show that sunflower seeds GHG emissions vary widely (between 0.3 and 22 kg CO_2eq kg_{seeds}^{-1}) and are highly depend on the LUC scenario. The highest emissions occurred when perennial cropland (no tillage, with manure) was converted into rainfed sunflower cultivation and the lowest when severely degraded grassland was converted into irrigated sunflower. The comparison of the GHG intensity of the two agricultural sunflower systems shows that irrigated sunflower had lower GHG emission due to the high productivity (3000 kg ha^{-1}) compared with rainfed (650 kg ha^{-1}).



SD:Severely degraded; NT: No tillage; mi:medium input; hi:highinput; w/:with manure; w/o:without manure;

Figure 2. GHG emissions of sunflower seeds

Life-cycle Impact Assessment (LCIA) results were calculated using the ReCiPe method (midpoint level and hierarchical perspective) [11] for the following 4 impacts categories: climate change (CC), terrestrial acidification (TA), marine eutrophication (ME), freshwater eutrophication (FWE). Figure 3 presents LCIA results for both irrigated and rainfed cultivation. Irrigated sunflower has lower ME impacts than rainfed sunflower (mainly due to a high productivity of irrigated sunflower). The most significant contribution to ME are cultivation emissions (mainly NO_3^-, but also NH_3 and NO_x emissions), that represent more than 96% of ME impact in all agricultural practices. TA impacts are slightly higher for irrigated sunflower, due to fertilizers (production and use), with NH_3 emissions representing about 43% of all emissions. FWE was 39% higher for irrigated sunflower than rainfed, due to the production and use of triple superphosphate fertilizer.

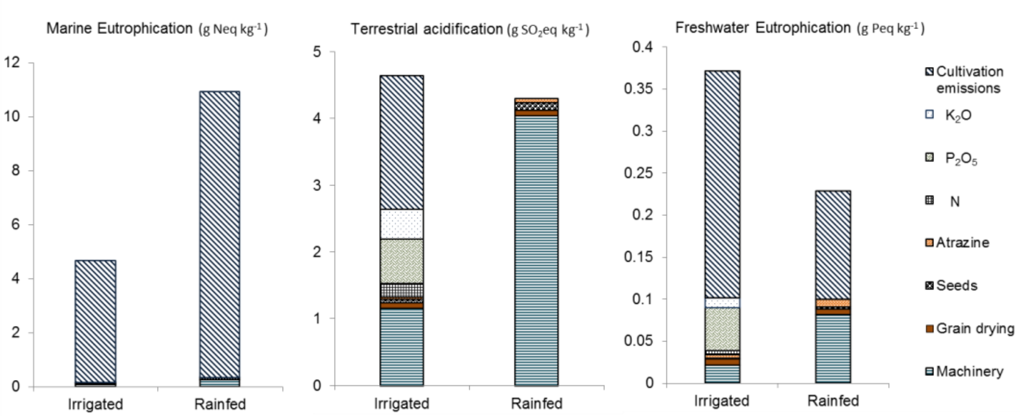


Figure 3. LCIA results (per kg of sunflower and no land use change).

CONCLUSION

Rainfed sunflower had higher environmental impacts in climate change and marine eutrophication essentially because of the low productivity per ha (650 kg $(ha*year)^{-1}$) and in ME due to high NO_3^- emissions. Sunflower cultivated in irrigated land (3000 kg $(ha*year)^{-1}$) had higher impacts in terrestrial acidification and freshwater eutrophication due to the use of fertilisers. A huge variation in the GHG intensity for sunflower seeds in Portugal was calculated (0.3-22 kg CO_2eq kg_{seeds}^{-1}), demonstrating that both agricultural practices and LUC scenarios can have an important influence on GHG intensity.

ACKNOWLEDGEMENTS

This research was supported by project ECODEEP (Eco-efficiency and Eco-management in the Agro Industrial sector, FCOMP–05–0128–FEDER–018643) and the Portuguese Science and Technology Foundation projects: MIT/SET/0014/2009, PTDC/SEN-TRA/117251/2010.

REFERENCES

[1] F. Figueiredo, É. Castanheira, F. Freire, "LCA of sunflower oil addressing alternative land use change scenarios and practices" Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector, Saint-Malo, France, 2012.

[2] C. Buratti, M. Barbanera, F. Fantozzi, "A comparison of the European renewable energy directive default emission values with actual values from operating biodiesel facilities for sunflower, rape and soya oil seeds in Italy". Biomass and Bioenergy, vol. 47, pp. 26-36, 2012.

[3] Directive 2009/28/EC of the European Parliament and of the council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, Official Journal of the European Union, 2009.

[4] F. M. Gírio, C.T. Matos, C.A. Oliveira, L. Silva, R. Bogel-Lukasik, R. Aguiar, "Typical green-house gas emissions in the cultivation phase of raw materials for the production of biofuels", Report from Portugal, 2010.

[5] T. Nemecek, T. Kägi, S. Blaser, "Life Cycle Inventories of Agricultural Production Systems", Ecoinvent report version 2.0, Vol. 15, Swiss Centre for LCI, ART, Duebendorf and Zurich, 2007.

[6] N. Jungbluth, "Erdöl. Sachbilanzen von Energiesystemen". Final report No. 6 ecoinvent data v2.0, Editors: Dones R., Vol. 6, Swiss Centre for LCI, PSI, Dübendorf and Villigen, 2007.

[7] A. Patyk and G. A. Reinhardt, Düngemittel - Energie- und Stoffstrombilanzen. Braunschweig/Wiesbaden, Germany: Vieweg Verlagsgesellschaft, 1997.

[8] IPCC, "IPCC Guidelines for National Greenhouse Gas Inventories - volume 4: Agriculture, Forestry and Other Land Use," Intergovernmental Panel on Climate Change (IPCC), Hayama, Japan, 2006.

[9] E. Veldkamp, M. Keller, "Fertilizer-induced nitric oxide emissions from

agricultural soils". Nutrient Cycling in Agroecosystems, vol. 48, pp. 69-77, 1997.

[10] V. Prasuhn, "Erfassung der PO4-Austräge für die Ökobilanzierung SALCA Phosphor". AgroscopeReckenholz - Tänikon ART, 2006.

[11] M.J. Goedkoop, R. Heijungs, M. Huijbregts, A. De Schryver, J. Struijs, R. Van Zelm, "A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level.", First edition report, 2008.