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Life Cycle Assessment of Flax and Camelina for Biodiesel Production in Sicily (Southern Italy)

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The use of renewable vegetable oils derived from oilseed crops could have serious environmental impacts especially regarding competition for land and emissions in air and water.
The environmental performances of *Linum usitatissimum* L. (Flax) and *Camelina sativa* L. (Camelina) oilseed crops for biodiesel production has been assessed by means of Life Cycle Assessment (LCA) approach, considering three steps: i) the cultivation, ii) oil seeds transport to pressing plant and seed pressing, iii) biodiesel production from vegetable oil by transesterification.
For the biodiesel from flax and camelina, more than 90% of the environmental impact is related to seed production, followed by the transesterification of raw vegetable oil and seed pressing at lab scale. The environmental performances are worst for the camelina mainly due to a lower seed yield. Nevertheless, these differences are slightly reduced thanks to the higher HHV (Higher Heating Values) of the camelina biodiesel.
For both the biodiesel, the main environmental hotspots are: the production of factors production, the nitrogen emissions associated with the application of fertiliser and the mechanisation of the field operations (in particular soil tillage and sowing) and the emission of N and P compounds related to fertilisers application.
In comparison with rapeseed (from data of Ecoinvent 3), the biodiesel from flax and camelina shows a higher environmental impact due to the higher consumption of fertilizers in rapeseed crop management.

1. Introduction

The production of first generation biofuels is mainly based on agriculture raw material such as oleaginous edible and non-edible plants. Brassica carinata, soybean, canola, sunflower, camelina and flax are the main used crops.
Besides to important socio-economical aspects (greater energy security, diversification of energy sources and agriculture, accelerated development of rural areas), the first generation biofuels can involve negative environmental impacts (e.g., competition for land, emissions of pollutants, biodiversity loss) (Castanheira et al., 2014) depending on the crops used and the efficiency of biodiesel production process. The choice of the proper crop can reduce the associated environmental impact (Escobar et al., 2009).
Linseed or flax (*Linum usitatissimum* L.) and *Camelina sativa* L. are two interesting crops for biodiesel production, above all for their adaptability to grow in different pedo-climatic conditions; nevertheless, until now, there is a lack of knowledge concerning the environmental performances of these two oil crops. Some studies addressed this sustainability aspect (Dangol et al., 2015; Godard et.al, 2013; Krohn and Fripp, 2012; Li and Mupondwa, 2014) but not in the Mediterranean areas.
In this study, using a Life Cycle Assessment (LCA) approach, the environmental impact of biodiesel from flax and camelina cultivated in Sicily (Southern Italy) was evaluated. LCA is a useful method to determine the environmental impact of products and services (ISO, 2006a; 2006b) and has been already applied to biofuels production processes (Escobar et al., 2009, Castanheira et al., 2014).

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2. Materials and methods

The environmental performances of *Linum usitatissimum* L. and *Camelina sativa* L. oilseed crops for biodiesel production has been assessed by means of LCA approach.

2.1 Description of the production systems

The production system has been divided in three subsystems:

- Seed production, this subsystem concerns the cultivation of these crops in typical Mediterranean environmental conditions, using a system based on no-irrigation and minimum use of fertilizers and pesticides.
- seed transport to pressing plant and seed pressing,
- biodiesel production by means of the transesterification of vegetable oil.

More details about the cultivation of the two oil crops can be found in Restuccia et al. (2013) and in Restuccia (2014).

2.2 Life Cycle Assessment

Four steps are foreseen by the LCA approach: 1) goal and scope, functional unit and system boundary definition, 2) inventory data collection, 3) impact assessment and 4) results interpretation (ISO, 2006a, ISO, 2006b).
In this study, the selected functional unit was 1 t of biodiesel produced from the camelina and flax while “cradle-to-factory gate” system boundary was considered (Figure 1); therefore, all the input related to crop cultivation (seeds, fuels, fertilisers, pesticides, capital goods), seed pressing (energy, capital goods) and transesterification (heat, electricity, chemicals, capital goods) were considered as well as the related emission into air, soil and water.

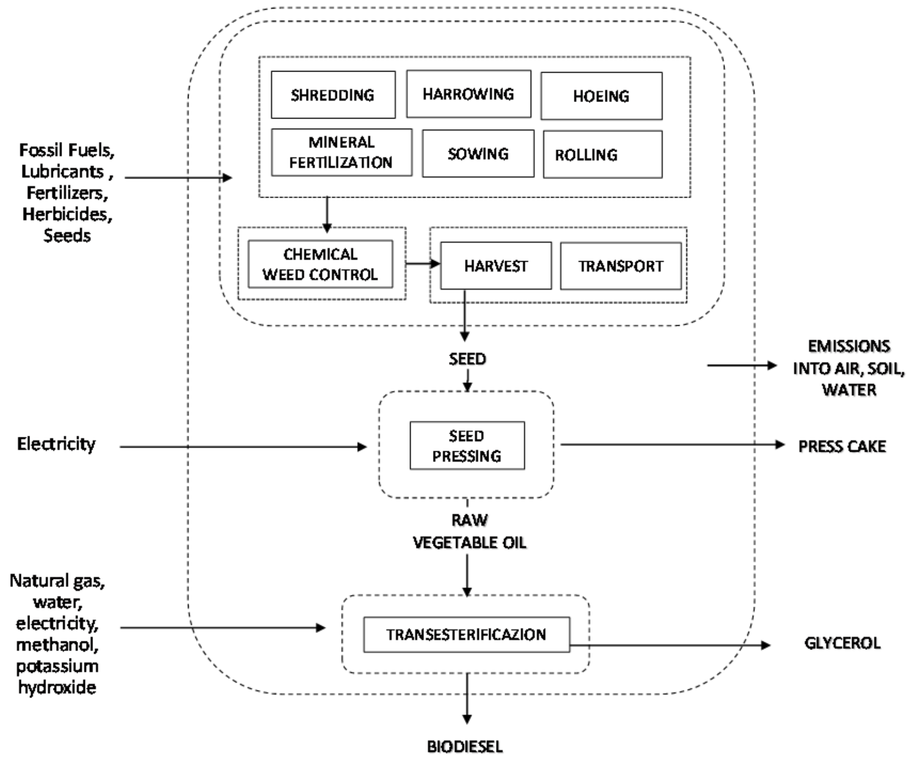

Figure 1: System boundary of the biodiesel production process

Primary inventory data were collected concerning seed production, pressing and transesterification yield. More in details, concerning raw oil production, seed pressing was carried out with a screw press in laboratory while regarding to transesterification yield lab scale tests in batch reactors were performed.
Secondary data from the Ecoinvent Database v.3 (Ecoinvent, 2012) were used for the production of seed, diesel fuel, fertilizers, pesticides, tractors and agricultural machines (equipment and combine harvester) as well as to consider the infrastructure of real scale pressing and transesterification plants.
Table 1 and 2 report the main inventory data measured during the cultivation trials and the lab-scale tests.

Table 1: Inventory data for seed production

Subsystem	Field Operation	Operative Machine	Tractor		Input		Time
			kW	kg	Product	Amount (ha^{-1})	$h\ ha^{-1}$
Soil Preparation	Shredding	Shredder	74	3500			3.17
	Harrowing	Cultivator	74	3500			0.97
	Hoeing	Rotary tiller	74	3500			1.33
Soil Tillage and Seeding	Mineral fertilization[1]	Fertilizer spreader	-	-	N P_2O_5	80 kg; 48 kg	-
	Sowing[1]	Seeder, mechanical distribution	74	3500	Seeds	39 kg	0.76
	Mineral fertilization[2]	Fertilizer spreader	52	3200	N P_2O_5	80 kg; 48 kg	0.17
	Sowing [2]	Seeder, pneumatic distribution	44	2420	Seeds	4.2 kg	1.55
	Rolling	Smooth roller	78	2540			0.57
Crop Management	Chemical weed control	Sprayer	52	3200	herbicide	0.5 dm^3 "linuron"[1] 0.5 dm^3 "metazachlor"[2]	0.30
Harvesting and Storage	Harvest	Combine harvester	167	10400			0.40
	Transport	Farm trailer					

1 = flax; 2 = camelina

Table 2: Yield during the three steps of the production process

Parameter	Flax	Camelina
Seed yield (t/ha)	1.45	1.10
Pressing yield (t raw vegetable oil/t seed)	0.279	0.284
Transesterification yield (t biodiesel/t raw vegetable oil)	0.980	0.965

Economic allocation between vegetable raw oil and press cake as well as between biodiesel and glycerol was carried out considering the following prices: 370, 740 and 140 €/t for press cake, biodiesel and glycerol respectively (Argus, 2016; ISMEA, 2016).
Using the Recipe mid-point method (Goedkoop et al., 2008), the following impact categories were evaluated:

- climate change (CC, kg CO_2 eq),
- ozone depletion (OD, mg CFC-11 eq),
- terrestrial acidification (TA, kg SO_2 eq),
- freshwater eutrophication (FE, g P eq),
- marine eutrophication (ME, kg N eq),
- particulate matter formation (PM, kg PM10 eq),
- mineral depletion (MD, kg Fe eq),
- fossil depletion (FD, kg oil eq).

3. Results and discussion

Table 3 reports the environmental impact for the biodiesel produced from flax and camelina's raw vegetable oil. Respect to biodiesel from flax, the one from camelina shows an increase of the environmental impact for all the evaluated impact categories (from +21% in Fossil Depletion to +30% in Terrestrial Acidification and Marine Eutrophication) except for Ozone Depletion (-3%). For this last impact category, the higher impact for

biodiesel from flax is related to the higher amount of seed used at the sowing (39 kg/ha for flax instead of 4.2 kg/ha for camelina).
The differences between the environmental impact of biodiesel from flax and the one from camelina are mainly related to the different seed yield. During the lab experimental tests, pressing and transesterification yield of the two crops did not present substantial dissimilarities, which means that the higher seed yield for flax (+28%) involves a lower environmental impact for raw vegetable oil production and, consequently, for biodiesel production (Figure 2).

Table 3: Environmental impact assessment for 1 ton of biodiesel

Impact category	Unit	Flax	Camelina
Climate change	kg CO_2 eq	4484	5702
Ozone depletion	mg CFC-11 eq	0.394	0.383
Terrestrial acidification	kg SO_2 eq	84.04	109.04
Freshwater eutrophication	g P eq	1.244	1.597
Marine eutrophication	kg N eq	119.42	155.65
Particulate matter formation	kg PM10 eq	15.18	19.60
Metal depletion	kg Fe eq	268.18	345.19
Fossil depletion	kg oil eq	821.43	994.12

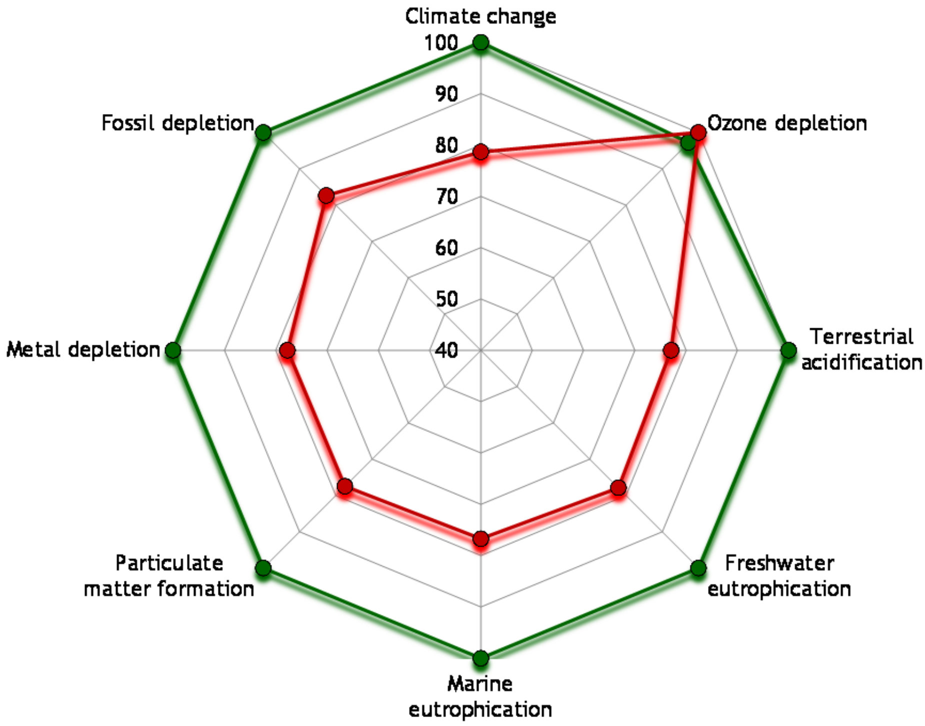

Figure 2: Relative comparison between the biodiesel produced from: flax (green) and camelina (red)

Figure 3 and 4 show the environmental hotspots for flax and camelina seed production.
Respect to camelina, flax has higher yield and, for 7 of the 8 evaluated impact categories, shows better environmental performances (impact reduction ranges from -7% to -30%). Respect to camelina, seed flax production is responsible for higher environmental impact for OD (+4%, due to higher amount of seed used at sowing).
The impact of seed pressing is considerably smaller respect to the one of trans-esterification and (above all) seed production. For pressing, the environmental impact is almost completely related to electricity consumption and, therefore, is proportionally lower for camelina (electricity consumption is equal to 0.06 kWh/kg of seed for camelina and 0.07 kWh/kg of seed for flax). The pressing represents less than 2% of biodiesel environmental impact for 6 of the 8 evaluated impact categories (PM, TA, FE, ME, MD and FD). OD is the only impact category in which the role of pressing is approximately 5% (5.4% for flax and 4.8% for camelina).

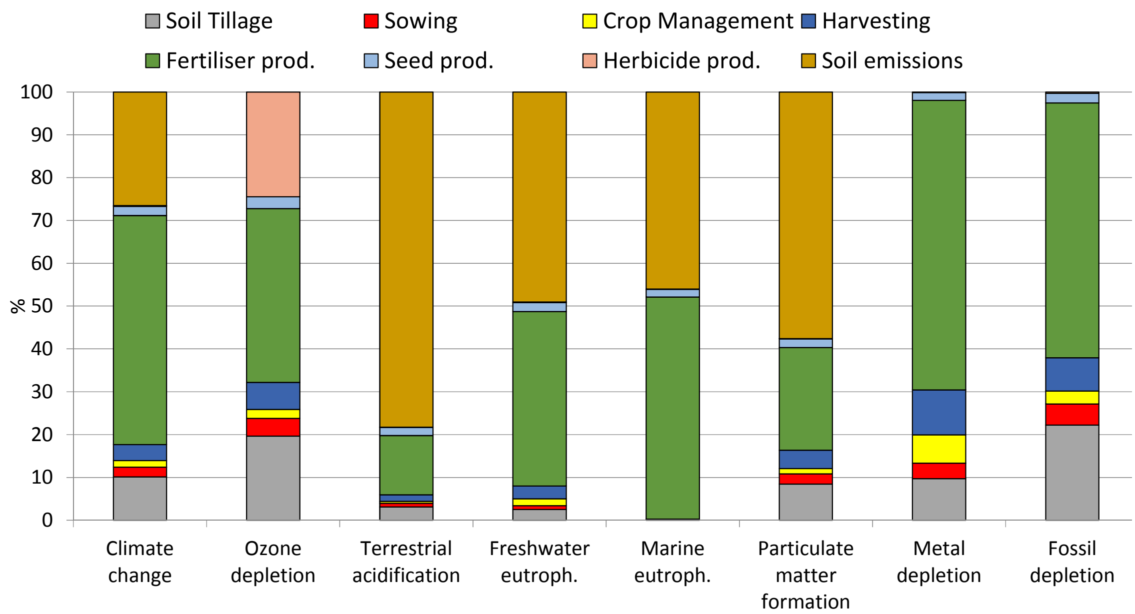

Figure 3: Environmental hotspots for the flax seed production.

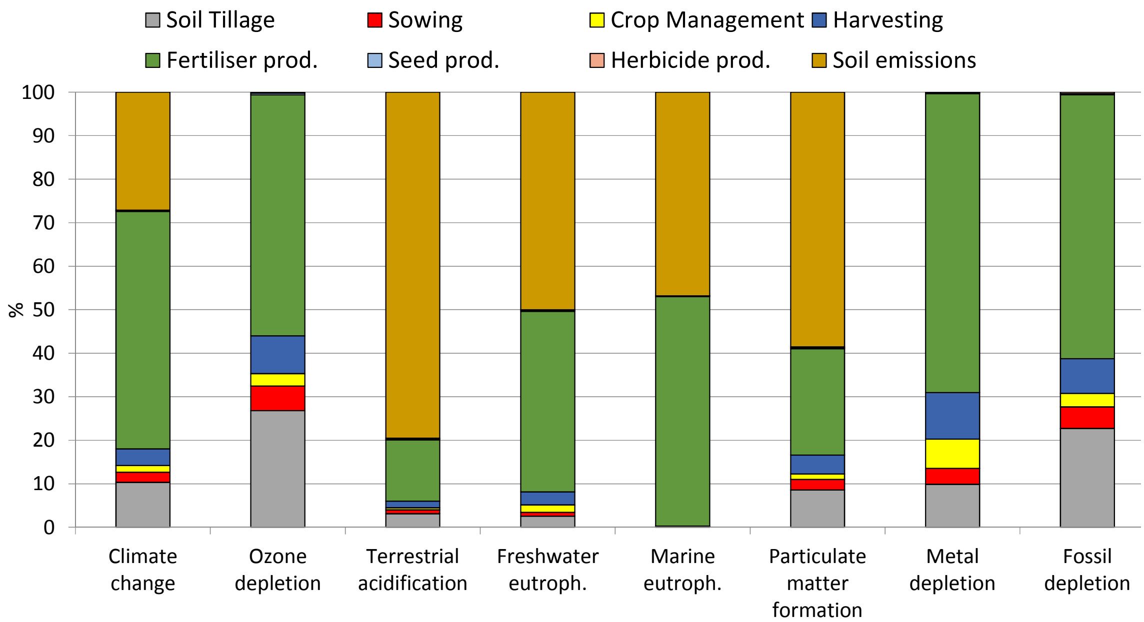

Figure 4: Environmental hotspots for the camelina seed production

The last step of the production process, the trans-esterification of the raw vegetable oil, is responsible for an environmental impact lower respect to the one of seed production but higher respect to the pressing. For both oil crops, this impact represents less than 2% of the total environmental load for TA and ME, is between 4% and 7% for CC, FE, MD and FD while for OD is about 10%.

4. Conclusions

This work performed life cycle assessment of biodiesel production from two unconventional oilseed crops, *Linum usisitatissimum* and *Camelina sativa* cultivated in Southern Italy (Siracuse province). The cultivation was carried out in Mediterranean environmental conditions using a production system based on no-irrigation and minimum use of fertilizers and pesticides. The biodiesel production chain was divided in three different sub-systems: seed production, seed pressing and transesterification of vegetable oils. All the main data were

collected during the experimental field of flax and camelina, the laboratory seed pressing of both crops and the laboratory transesterification. Among the different subsystems, seed production is by far the most responsible of the environmental impact of the produced biodiesel (more than 80%); the role of seed pressing and transesterification is limited and usually lower than 2%.
Between the two biodiesel, the one produced from flax shows better environmental results. Respect to camelina, flax has higher seed yield and, except for Ozone Depletion (due to higher amount of seed used at sowing), shows lower environmental impacts (ranging from -20% to -30%).

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