Bioenergy crops production in Italy: environmental impacts and economic performances

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Summary

Sustainable energy production is one of the most important environmental topics of the 21st century. Paper aims to identify and compare the sustainability of rapeseed and sunflower cultivation for energy purpose in Italy, by considering environmental and economic performances at farm level. Twelve farming units –six farms per each crop- were extracted from a sample of 400 Italian farms by means of a cluster analysis in order to identify representative units for each crop. Using an Attributional Life Cycle Assessment method, the carbon footprint in terms of greenhouse gas (GHG) emissions of the twelve units was measured up to the farm gate. Three rapeseed farms were the lowest impactful units within the whole sample. Practices of intensive farming with high fertilization and mechanization were responsible for the greatest environmental impacts. Where the level of yields was low, impacts were still higher. In order to combine the environmental and economic assessment, the eco-efficiency ratio was applied to measure the net value added per Mg of GHG emitted to the atmosphere. Findings showed that the three rapeseed farms with the best environmental performance had also the highest eco-efficiency ratio. Results obtained in the baseline scenario and referred to 1Mg did not change significantly when the carbon footprint was measured in terms of heating value as 1 MJ. Paper results about the best environmental and economic performances between the two crops may give useful insights in choosing which bioenergy crop and cultivation practice to prefer in order to combine the two dimensions of sustainability.

Keywords: bioenergy crops; Italian farms; cluster analysis; carbon footprint; eco-efficiency ratio,

JEL Classification codes: Q15 Agriculture and Environment, Q42 Alternative Energy Sources, Q51 Valuation of Environmental Effects, Q12 Micro Analysis of Farm Firms

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1. INTRODUCTION

Sustainable energy production is one of the most important environmental topics of the 21st century. The potential environmental benefits that can be obtained from replacing petroleum fuels with bioenergy derived from renewable biomass sources are the main reasons for promoting the production and use of bioenergy.

At European level, oilseed production in 2016/2017 is of about 31.1 million of tones, among which 20 million tons of rapeseed and 8.5 million tonnes of sunflower (EC, 2017). Energy crops have strongly grown over the last years in Italy (Bartoli et al., 2016).In Italy, according to ISTAT (2016), sunflower cultivation covered 114,000 hectares while rapeseed crop covered 12,000 hectares in 2015.

Environmental performances of bioenergy resources may differ among crops. Likewise, economic returns are different and may favour one crop instead of another, regardless of their environmental impacts. For this reason, it is interesting to assess both the environmental performances of different bioenergy crops, and to consider their economic return in order to jointly minimize environmental impacts and maximise economic values. Within this context, paper aims to identify and compare the sustainability of rapeseed and sunflower cultivation for energy purpose in Italy, by considering environmental and economic performances at farm level.

1.1. Literature background

Greenhouse gas emissions (GHG) are one of the main impacts to consider when assessing the environmental sustainability of different crops and reporting the climate change impact of their production.

Buratti et al. (2012) calculated the GHG emissions of biodiesel from sunflower and rapeseed produced in Italy, according to the rules defined in the European Union Renewable Energy Directive 2009/28/EC (RED). Authors showed that GHG emissions were higher for rapeseed (with 32g CO_2-eq per 1 MJ for sunflower, and 38g CO_2-eq per 1 MJ for rapeseed). Furthermore, their study highlighted that over the whole supply chain, cultivation is the step characterized by the highest environmental impacts, both for sunflower (67%) and rapeseed (69%). Similar results were obtained in the study of Spinelli et. al. (2013) where the agricultural phase emerged as the highest impactful step in the whole production line of biodiesel from sunflower in the Province of Siena (Tuscany). On the contrary, Schmidt (2015) showed that the GHG emissions were higher for sunflower oil (with 760 Mg CO_2-eq per 1 Mg refined oil) than for rapeseed oil (with 262 Mg CO_2-eq per 1 Mg refined oil).

Besides considering environmental impacts, crop production should be assessed under an economic perspective. The eco-efficiency is a measure of sustainability that directly links environmental impacts with economic performances (Kicherer, 2007; Muller et al. 2015; Saling, 2016). So far, the concept of eco-efficiency has been mainly used to support economic decisions, such as assessing acquisitions and changes in product lines or exploiting new market opportunities by demonstrating stewardship for natural resources (Saling, 2016). According to Honkasolo et al. (2005), eco-efficiency concerned three main goals: the reduction of resource consumption, the reduction of environmental impacts, and the increasing value of products. Methods and tools for calculating eco-efficiency are controversial (Huppes and Ishikawa 2005; Muller et al. 2015) in terms of which environmental and economic dimensions to involve. The economic performance in an eco-efficiency analysis can be reported in monetary units as sales or as “value added” by measuring the values of sales minus the costs of goods (Muller et al. 2015). A similar formula is used by WBCSD (2000) that defines the eco-efficiency ratio as net sales or quantity of goods produced/ environmental impact. Few studies applied the indicator to agricultural products in order to estimate the net profit added per kg of greenhouse gases (GHG) emitted into the atmosphere (Muller et al., 2015). To our best knowledge, there are no studies that applied an ecoefficiency analysis to rapeseed and sunflower energy crop production.

Paper aims to contribute to the above literature by assessing and comparing the environmental sustainability of rapeseed and sunflower cultivation and their ecoefficiency performance.

2. DATA AND METHODS

2.1. Sample data and representative units

A sample of 400 Italian farms is considered in the study. In particular, 251 farms with rapeseed and 145 units with sunflower crops were considered for a total of 2,751 and 1,465 hectares respectively. The 400 farms engaged in a conversion program from sugar beet towards energy crops that was managed by three national buyers, PowerCrop SpA, S.F.I.R. SpA and Co.Pro.B., S.F.I.R. and Co.Pro.B. are two sugar factories. Co.Pro.B. is a cooperative of farms that since 2013 has undertaken a diversification process of sugar beet production towards renewable energy production. S.F.I.R. SpA, besides being involved in the sugar production, converts and develops sugar refineries into biomass power plants. PowerCrop SpA develops energy from the biomass short supply chain by building high-efficiency biomass power plants in Italy. The selling price of the two energy crops analysed in this study and sold to the three buyers - including the withdrawal of the products from the farms- was linked to the cultivation contracts. For this reason, in the economic assessment the price of the two crops was the same among farms, respectively for all farms with rapeseed (390 €/Mg) and with sunflower (320 €/ Mg), as set in the cultivation contracts.

For each farm, collected data referred to farm size (ha), yield (Mg/ha), intensity of mechanization (kwh/ha), quantity of phosphorus (kg P_2O_5 /ha), potassium (K_2O, kg/ha), nitrogen (kg N/ha) used in mineral fertilisers, and herbicide (l/ha).

Data highlights a quite similar situation between rapeseed and sunflower cultivation, both in the mean value and in the standard deviation of cultivated hectares and yield. Strong differences between the two crops were observed in the intensity of mechanization and in the usage of chemical input along the cultivation process, and reported higher average values for sunflower compared with rapeseed. The variability in the distribution of indexes within the samples was higher for rapeseed than for sunflower cultivation, most of all as far as phosphorous and potassium usage (Table 1).

Table 1. Descriptive statistics of farm indicators for the two oil crops

	Rapeseed			Sunflower		
	mean	std dev	coeff. of var.	mean	std dev	coeff. of var.
Cultivated area (ha)	10.96	13.33	1.22	9.70	13.90	1.43
Yield (Mg/ha)	2.14	1.16	0.54	2.70	1.10	0.41
N (kg/ha)	77.73	59.62	0.77	110.66	33.15	0.30
P_2O_5 (kg/ha)	16.51	30.53	1.85	62.08	32.49	0.52
K_2O (kg/ha)	2.03	12.25	6.04	4.91	3.14	0.64
Herbicide (l/ha)	2.15	2.08	0.97	2.31	2.15	0.93
Machine power (kWh/ha)	588.83	284.80	0.48	793.38	255.47	0.32

In order to synthesize the variability within the two samples according to management and cultivation practises, we carried out a multivariate analysis to obtain a smaller number of case studies to be considered in the eco-efficiency assessment. A cluster analysis was separately applied to rapeseed and sunflower units based on the standardized values of variables related to their yield, to the intensity of mechanization and the N amount (K_2O e P_2O_5 variables were not considered due to the high variability inside the sample and to several zero values).

For each crop, cluster analysis followed a hierarchic clustering procedure as an explorative approach to identify the range of cluster's number that better partitioned the initial sample. For both crops, this range was identified between five and eight clusters' solution. In a following step, for each number of cluster included in the range previously identified, a k-means method was applied to identify cluster's solutions. Due to the k-means sensitiveness from initial clustering center, a number of 100 iterations was considered and the solution with the higher percentage of explained variance (ratio between the sum of squares/total sum of squares) was taken as final partition.

For both crops, the best solution split the whole sample into six clusters. Table 2 reports a summary of the cluster's solutions and the percentage of farms within each cluster group.

Farms unit with the lower distance from cluster's centroid was chosen as the representative farm of each cluster and used in the eco-efficiency analysis.

As showed in Table 3, as far as rapeseed cultivation, three units refer to small farms with less than 2 hectares of which: the two smallest farms obtained a good yield, but one of them (code 1502R) showed the highest amount of N input and mechanization intensity. The third rapeseed small farm (24013R) represents a cluster of farms with very low yield and input levels; this cluster was quite numerous and included the 21% of rapeseed farms. Two farms with rapeseed crop had an extension between 7 and 10 hectares: the biggest farm (2503R) had a higher yield while lower inputs and mechanization intensity than the other farm (21008R); these units represent over half of the rapeseed sample, respectively the 35% and the 16% of total units. Finally, the sixth representative rapeseed farm (2104R) represents a cluster of big farms with high yields and chemical inputs, but with a low mechanization level; this cluster includes only the 6% of units in the rapeseed sample.

As far as sunflower cultivation, three farms had less than 5 hectares. The smallest one (1502S) had a low yield and zero N input, but a high intensity of herbicide use and mechanization; the second smallest farm (18003S) represents a cluster of units with high yield, N input and kWh/ha, but with a low herbicide input compared with the third small farm (1503S). Two farms with a medium extension were highly different in that one of them (1602S) had a lower yield but a higher intensity of chemicals and mechanization compared with the other unit (1401S); these farms represent respectively the 14% and 35% of units in the sunflower sample. Finally, the sixth cluster with sunflower cultivation (2591S) was representative of a group of large farm (3% of the sample) with the highest herbicide input and the lowest mechanization level among sunflower units.

Table 2. Cluster's solutions

Crops	Percentage of farms within clusters' solution						betweenSS/
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	totalSS (%)
Rapeseed	20.8	17.4	5.8	15.5	35.3	5.3	65.8
Sunflower	8.2	15.8	13.0	34.9	13.7	14.4	69.3

Table 3. Representative farm's units

Cluster no.	Crop	CODE	Ha	Yield	totN	herbicide	kWh/ha
1	Rapeseed	2401R	1.21	0.32	0	1.07	606.81
2	Rapeseed	2301R	0.95	4.32	96.90	1.79	670.24
3	Rapeseed	2104R	26.00	3.97	103.50	6.12	509.41
4	Rapeseed	2100R	7.00	2.79	98.50	2.00	571.07
5	Rapeseed	2503R	9.50	3.05	96.84	1.89	418.36
6	Rapeseed	1502R	1.00	3.35	128.00	2.00	875.07
1	Sunflower	1502S	2.87	2.05	0	2.47	774.34
2	Sunflower	1800S	4.40	3.01	162.05	0.68	769.45
3	Sunflower	2591S	36.55	2.43	95.76	6.02	475.40
4	Sunflower	1401S	10.53	1.76	85.47	1.33	672.40
5	Sunflower	1503S	4.81	2.58	103.95	2.08	601.47
6	Sunflower	1602S	8.30	0.93	102.41	1.69	1093.37

The twelve representative farming units identified by applying cluster analysis were considered in the environmental and eco-efficiency analysis.

Finally, looking at both crop's farms, it seemed that the smallest units, while having good yield, were intensive in the use of nitrogen and in the mechanization level; the biggest units emerged for high herbicide inputs but low mechanization intensity. Due to this complex picture, it is hard to draw conclusions about farm units with the best environmental performance for each crop and between crops. For this purpose, an environmental analysis was applied to the twelve representative farming units extracted by means of cluster analysis.

2.2. Environmental and eco-efficiency analysis

An Attributional Life Cycle Assessment (ALCA) method based on the ISO 14040:2006 standard was applied to measure the GHG emissions of the twelve representative units.

The LCA system boundary (fig. 1) considered all of the agricultural processes during the crop cycle, from the tillage operations to the farm gate (including machinery, fertilisers, seeds, herbicides, pesticides production and the diesel consumption). Primary data included the technical characteristics of tractors and agricultural equipment, diesel consumption, types and quantity of herbicides and fertilisers used. Secondary data -including tractor and machinery production, maintenance and disposal of tractor and machinery, fertilizers and herbicides production- came from the Ecoinvent database (v 3.0). The Simapro code database 8.0.4.30 of Prè Consultants was used to assess the environmental performance of the studied production systems. In the production of energy crops, the land use change (LUC) associated, both direct and indirect, can produce changes in the carbon from the soil and vegetation (Iriarte et al., 2010). In study farms, direct land use change did not occur because the rape and the sunflower are annual oil crops that were cultivated in croplands that have not undergone any land-use conversion for a period of more than 20 years (IPCC 2006; European Commission, 2010; Spugnoli et al., 2012). Moreover, the assessment of indirect land use change

(ILUC) did not fall within study aims, also because it is still debated the issue of how including indirect land use change in a sustainability biofuel assessment (Carneiro et al., 2017; Spugnoli et al. 2012).

In the baseline scenario, the functional unit was 1Mg of rapeseed and sunflower (1 Mg). A sensitivity analysis on functional unit was applied, switching from 1 Megagram of seeds to 1 Megajoule (MJ) with a High Heating Value (HHV) of about 0.0278 MJ per 1Mg (Saidur et al., 2011) of rapeseed seeds, and of 0.0295 MJ per 1Mg of sunflower seeds (Juan et al., 2010).

Furthermore, the analysis focuses on the economic performance of the two energy crops per ha of biomass cultivation and combines the environmental and economic assessment. The eco-efficiency ratio was applied to measure the net value added per kg of GHG emitted to the atmosphere. The gross value added was defined as the difference between total revenues and variable and fixed costs (except labour cost, depreciation and interest loan payment). It was calculated based on primary data collected from the farm.

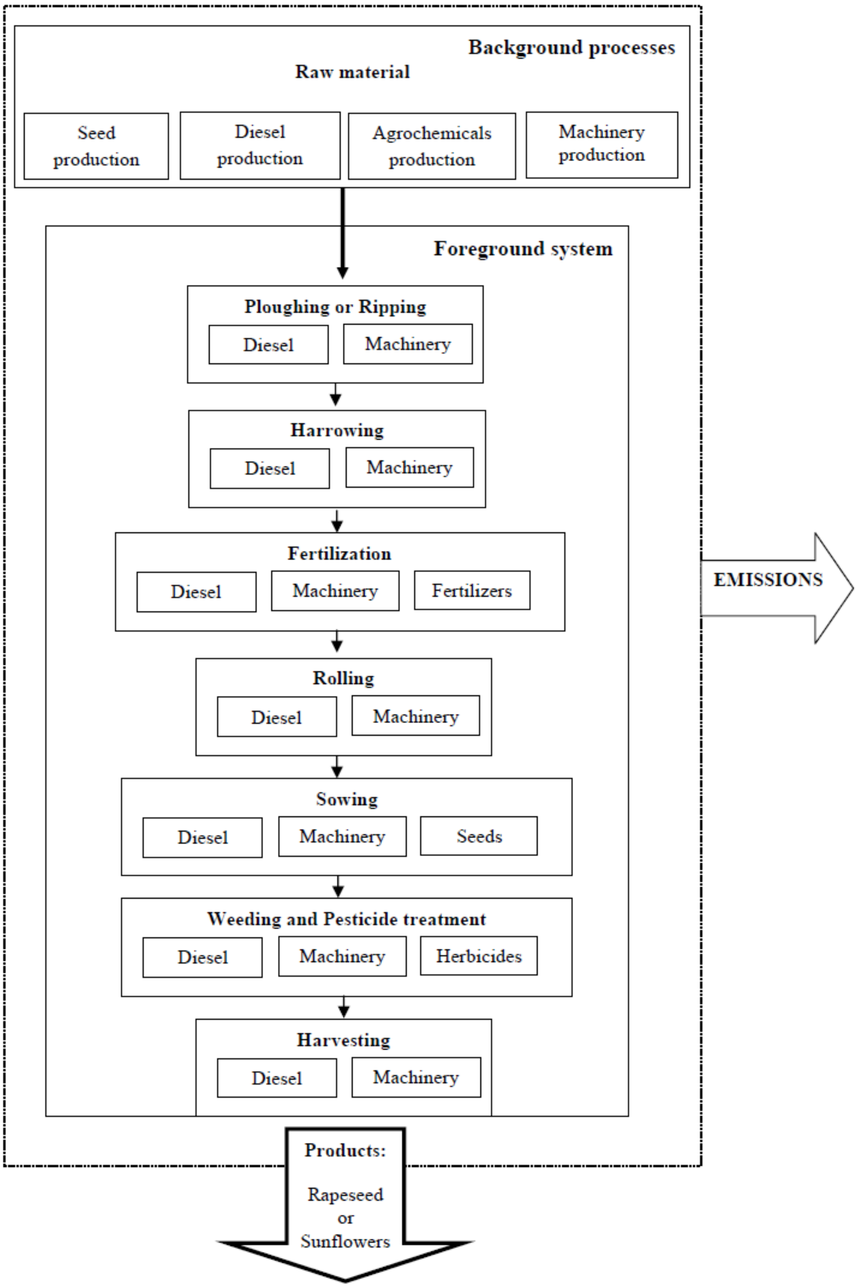

Figure 1. LCA sistem boundaries

3. RESULTS AND DISCUSSION

The carbon footprint was calculated to compare the environmental burden of the two energetic crops and to measure the eco-efficiency ratio in terms of gross value added (GVA) per kg of GHG emitted to the atmosphere. A sensitivity analysis on the functional unit (switching from 1Mg of seeds cultivated to 1 MJ) was carried out and main findings were discussed.

3.1. The carbon footprint of rapeseed and sunflower

The carbon footprint is the amount of greenhouse gases emitted during a product's lifecycle (Pandey and Agrawal, 2014; Röös et al., 2014). It is an important indicator to report the climate change impact of products (Roma et al., 2015).

In the study, the carbon footprint of 1Mg of rapeseed and sunflower cultivation was defined as the sum of all GHGs emitted within the system boundaries and expressed in CO_2 equivalent (CO_2-eq) using the IPCC, 2007 method (100 years life span).

The GHG impact analysis allowed identifying the most impactful processes among the twelve representative farms (Table 4).

Table 4. Carbon footprint of 1Mg: rapeseed and sunflower farms

Unit	2401R	2301R	2104R	2100R	2503R	1502R	1502S	1800S	2591S	1401S	1503S	1602S
kg CO_2eq per Mg of seed	2346	308	375	512	469	597	526	562	598	798	643	2245

Results showed that the carbon footprint of rapeseed cultivation was on average about of 768 CO_2eq per Mg; while that of sunflower cultivation was on average of about 895 CO_2eq per Mg.

Comparing findings about the carbon footprint of 1Mg of rapeseed and sunflower it emerged that three rapeseed farms (2301R, 2104R and 2503R) were the lowest impactful units in the whole dataset, irrespective of the energetic crops studied. These results were mainly due to a higher yield in the three farms (and to a single fertilization phase in one farm 2503R). The fourth rapeseed farm (2100R) with a carbon footprint of 512 kg CO_2eq per Mg of seed was followed by the 1502S farm (with 526 kg CO_2eq per Mg) that was the lowest impactful unit among sunflower farms. The 2401R and 1602S units were the highest impactful farms in terms of GHG. Comparing the lowest impactful farms for each crop, the 1502S sunflower farm showed higher GHG emissions (+70%) than the 2301R rapeseed unit. On the other hand, while among rapeseed farms the percentage gap from the best unit (2301R) was sensible (+21% in 2104R unit; +52% in 2503R farm), among sunflower units the percentage gap from the best unit 1502S farm was negligible (+ 6% in 1800S unit).

The carbon footprint of farms was different from each other, mostly because each farm had different values of seeds yield, fuel consumption type and amount of nitrogen fertilizers used. In all farms, the major contributions to the GHG emissions was due by nitrogen fertilizers production, diesel consumption and N_2O emissions due to nitrogen denitrification into the soil. In many farm units, ploughing and harvesting operations consumed the largest quantity of diesel in both energetic crops cultivation.

Study findings related to the rapeseed crop were on average lower than other studies. Mousavi-Avval et al. (2016) applied a life cycle assessment of rapeseed production and showed that global warming potential was 1.18 Mg CO_2eq per Mg of rapeseed, of which 845 kg CO_2eq was due to on-farm emissions. Bieńkowski et al (2015) identified the carbon footprint of rapeseed crop in Poland and showed that on average it was 794.2 kg CO_2eq per Mg of seeds; in Finland the carbon footprint for rapeseed cultivation was assessed in 1,480 kg CO_2 eq per Mg (Saarinen et al., 2012).

As far as sunflower crop, the literature reports very different results. Eady et al. (2011) assessed a carbon footprint of 340 kg of CO_2eq per Mg of sunflower cultivated in Australia. The study of Spugnoli et al. (2012) measured in 994 kg of CO_2eq per Mg the impact of sunflower cultivated in Italy. Study results were in line with the work of Chiaramonti and Recchia (2010) that assessed a biofuel chain in Italy and showed that the GHG coming from sunflower cultivation ranged from 500 to 2,140 kg CO_2eq per Mg of seeds.

Differences in the measure of the carbon footprint of energetic crops between above literature and this study depend on two main aspects: a different yield per hectare; differences in the agricultural practices used. In fact, according to some Authors (Eady et al., 2011; Chiaramonti and Recchia, 2010), the carbon footprint is influenced by both the yield per hectare, the practice of fertilization and the amount of fertiliser used; furthermore, different data for “field inputs” parameters among studies lead to differences in environmental results.

Despite the variability of values reported in the literature assessing the carbon footprint of the single crop, findings from studies comparing the two crops supported our conclusion about the lower impact of rapeseed than of sunflower cultivation. According to Iriarte et al. (2010), the carbon footprint associated with rapeseed crop was 820 kg CO_2eq per Mg seeds, while GHG emitted by sunflower cultivation was 890 kg CO_2eq per Mg seeds. Al-Mansour and Jejčič (2014) showed that in Slovenia GHG emissions coming from rapeseed cultivation ranged from 203.7 to 354.7 kg of CO_2eq per Mg of rapeseed produced, while sunflower crop emitted from 224.7 to 318.4 kg of CO_2eq per Mg. In Al-Mansour and Jejčič (2014) study, the lower emissions of GHG gases compared with our results are due to the exclusion of emissions from herbicide/pesticide and fertilizer productions that, instead, were included in our study.

Finally, the assessed carbon footprint of rapeseed and sunflower cultivation allows identifying for each energetic crops the least impacting farm, respectively the 2301R and 1502S farms. The lowest impact per each crop is mainly due to a high yield that permits to spread the inputs and the environmental costs to a higher output (in the 2301R farm), or to a reduced amount of N fertilizer used (in the 1502S farm). Farm 2301R used a medium amount of N (96.89 kg N/ha) that allowed producing a good yield (4.32 Mg/ha) compared with other farms. Farm 2100R used a lower amount of N (52.5 kg N/ha) and the farm 2400R did not used fertilizers at all. On the other hand, farms 1502R and 2104R, while using a higher amount of fertilizers (128.0 and 103.5 kg N/ha, respectively), had a yield lower than 4 Mg/ha. This result is in agreement with the study of Rathke et al. (2006) that showed a less efficient absorption of available soil nitrogen in rapeseed crop cultivation; furthermore, correct fertiliser management may reduce the input of more than 50% of nitrogen fertilisers (Palmieri et al., 2014). If the yield results not sufficient to justify the amount of input used, the final environmental burden results in substantial impacts.

With 36 kg N/ha applied and a yield of 2.05 Mg/ha (0.02 kg N used per kg of seed produced), the farm 1502S showed a much more efficient utilization of N than the farm 1503S that, with 114.8 kg N/ha used, it reached a seeds production of 2.54 Mg/ha (0.05 kg N used per kg of seed produced). By contrast, farm 1602S obtained a yield of just 0.93 Mg with an application of 102.5 kg N/ha. These results could be explained by the study carried out by Montemurro and De Giorgio (2004), that showed how in Mediterranean contexts sunflower yield is limited by the cropping system adopted, the soil water regime, and the residual N in the soil, and that the additional N application has a limited effect. The study highlighted that intermediate N fertilizer level (50 kg N/ha) results in a good balance among productive parameters, N use efficiency indices, and, consequently, lower pollution risks, confirming that almost half of the N fertilizer remains in the soil at the end of the cultivation cycle; for this reason, sunflower could absorb a high amount of residual N from the soil and produce yield with low N input indicating that N fertilizer should only be applied annually when required (Montemurro and De Giorgio, 2004).

3.2. Measuring the eco-efficiency of rapeseed and sunflower

The eco-efficiency analysis was applied to the twelve representative farming units. The eco-efficiency of each crop cultivation was computed dividing its gross value added by the environmental impact (WBCSD, 2000).

Findings showed that positive eco-efficiency value (Table 5) ranged from 0.82 kg CO_2eq (2301R unit) to 0.29 (1502R) for rapeseed units, and from 0.30 (2591S unit) to 0.03 kg CO_2eq (1401S unit) for rapeseed units. In other words, rapeseed cultivation resulted more eco-efficient than sunflower crop. These results were mainly due to a higher yield in the rapeseed farms, so confirming that eco-efficiency ratio can be higher in crops that showed higher yields (Kulak et al., 2013). Among rapeseed units, the best environmental performance of 2301R unit is in pair with a high value added, while under an economic viewpoint, the unit had lower total costs than other sunflower farms. On the other hand, the 1502S farm with the lowest environmental burden, had costs higher than other sunflower farms and a quite low eco-efficiency ratio (0.12 € per kg CO_2eq). Finally, the 1602S and 2401R units were the worst examples under both environmental and economic perspectives.

A deep discussion of specific findings is usually quite difficult in LCA studies because of differences in the applied approaches and in several conditions related to study cases and assessed crops. Moreover, the selection of different data for field inputs and outputs parameters (i.e fertilizers quantity used, yield,.....) lead to differences in environmental results. Furthermore, to our best knowledge, there are not studies dealing with both GHG and eco-efficiency indicators in comparison between the two bioenergy crops analysed in this work.

Table 5. Rapeseed and sunflower farms: economic data (€/Mg) and eco-efficiency values

Rapeseed farms	**2401R**	**2301R**	**2104R**	**2100R**	**2503R**	**1502R**
Total GVA (Gross Value Added (€/Mg)	-1277	253	230	196	265	173
Total GWP (kg CO_2 eq per €/Mg)	2346	308	375	512	469	597
Total eco-efficiency (total GVA/total GWP)	**-054**	**0.82**	**0.61**	**0.38**	**0.56**	**0.29**
Sunflower farms	**1502S**	**1800S**	**2591S**	**1401S**	**1503S**	**1602S**
Total GVA (Gross Value Added (€/Mg)	64	139	177	28	140	-597
Total GWP (kg CO_2 eq per €/Mg)	526	562	598	798	643	2245
Total eco-efficiency (total GVA/total GWP)	**0.12**	**0.25**	**0.30**	**0.03**	**0.22**	**-0.26**

Source: self-elaboration based on economic data from firm's annual report - year 2016-.

3.3. Sensitivity Analysis

The sensitivity analysis was done switching the functional unit from 1Mg to 1 MJ of rapeseed and sunflower. As above mentioned, the High Heating Value (HHV) for rapeseed was 0.0278 MJ per Mg (Saidur et al., 2011), while for sunflower it was 0.0295 MJ per Mg (Juan et al., 2010).

Table 6. Carbon footprint of 1Mg and 1 MJ: rapeseed and sunflower farms

		Functional unit	
Rapeseed farms	**Unit**	**1Mg**	**1 MJ**
2401R	kg CO_2 eq	2346	0.085
2301R	kg CO_2 eq	308	0.011
2104R	kg CO_2 eq	375	0.013
2100R	kg CO_2 eq	512	0.019
2503R	kg CO_2 eq	469	0.017
1502R	kg CO_2 eq	597	0.022
Sunflower farms		**1Mg**	**1 MJ**
1502S	kg CO_2 eq	526	0.018
1800S	kg CO_2 eq	562	0.019
2591S	kg CO_2 eq	598	0.020
1401S	kg CO_2 eq	798	0.027
1503S	kg CO_2 eq	643	0.022
1602S	kg CO_2 eq	2245	0.080

Previous findings obtained according to 1Mg as functional unit did not significantly changed when the carbon footprint is converted in terms of 1 MJ (Table 6). Among the twelve representative farming units, results showed again that the same three rapeseed farms (2301R, 2104R and 2503R) were the lowest impactful units in the whole sample, irrespective of the energetic crops studied. The 1502S was the lowest impactful unit among sunflower farms, while the 2401R and 1602S units were the highest impactful farms. Comparing the farm with the lowest impact for each crop, the 1502S sunflower farm showed GHG emissions 63% higher than those emitted from 2301R rapeseed unit.

4. CONCLUSION

The paper focused on the carbon footprint of oilseed rape and sunflower cultivations for energy purposes in Italy. Twelve representative farming units were extracted from a sample of 400 farms by applying a cluster analysis. Using an Attributional Life Cycle Assessment (ALCA) method, the carbon footprint of the twelve units was evaluated. Successively, study focused on both the GHG emissions and the economic performance of the two energy crops per 1Mg. In order to combine the environmental and economic assessment, the eco-efficiency ratio was applied to measure the net value added per Mg of GHG emitted to the atmosphere.

At a global glance, the LCA analysis showed that carbon footprint referred to 1Mg is influenced by the yield per hectare: the least impactful unit had the highest yield and, alternatively, the most impactful had the lowest yield. Rapeseed farms were more productive and less impacting than sunflower farms. This finding is in line with other LCA studies showing that productivity is a crucial factor in environmental analysis because the environmental impact in relative terms decreases at increasing yields.

Under the environmental perspective, rapeseed resulted more sustainable than sunflower crop, as observed in other study, both with reference to the seeds yield and value added and to their global warming potential and energy power.

The study may have some limitations.

The analysis was referred to a sample of twelve units. Anyway, the sample was extracted from a larger number of farms and primary data were collected. LCA studies often refer the environmental assessment to single case studies and make use of literature data.

The economic analysis was based on the prices set in the cultivation contracts that all farms signed with three national buyers. Anyway, having applied uniform selling prices respectively to rapeseed and sunflower crops, rather than being a limit, it has the advantage of highlighting differences in costs incurred along the production cycle that mirrored the different intensity of cultivation practices.

Defining the conditions for the best environmental and economic performances of rapeseed and sunflower crops and comparing the two bioenergy sources is an interesting research issue to further explored and to which study findings may provide suggestions about which crop and cultivation practices to prefer under the two sustainability perspectives.

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