Environmental and economic analysis of the organic and conventional extra-virgin olive oil

Bruno Notarnicola , Giuseppe Tassielli*, Giuseppe Martino Nicoletti***

Jel classification: Q120, L660

Abstract

Olive oil represents a relevant productive sector in Puglia, a region of the South of Italy, since it stands for more than 50% of the whole Italian output and about 18% of the EU output. In the last years, the production of organic extra virgin olive oil has been steadily increasing due to new consumer behaviour and to the nutritional and healthiness quality of these products. However, organic extra-virgin olive oil still remains a niche product because of its market price remarkably higher than that of other oils and fats. In this paper the production systems of the conventional and organic extra-virgin olive oil have been compared, in order to assess their environmental and cost profiles, and to verify if the two dimensions – environmental performances and costs - go along the same direction. The methodologies used are the Life Cycle Assessment (LCA), as stated by ISO 14040 rules, concerning the environmental profile, and the Life Cycle Costing (LCC), a new tool used to account for the total costs (internal and external) of a system. The results substantiate that the organic system has a better environmental profile compared to the conventional one, but scores worse in the cost profile if the external costs are not accounted for.

Résumé

L'huile d'olive représente un secteur productif très important dans les Pouilles, région du sud de l'Italie, étant donné qu'elle couvre environ 50 % de la production italienne et environ 18% de la production européenne. Ces dernières années, la production d'huile d'olive vierge extra biologique a connu un accroissement significatif imputable non seulement à une nouvelle sensibilité des consommateurs mais aussi aux qualités nutritionnelles et de salubrité de ce produit. Toutefois, l'huile d'olive vierge extra biologique reste encore un produit de niche à cause de son prix de marché nettement supérieur à celui des autres huiles et graisses. Dans cet article, nous avons comparé les filières de production de l'huile vierge extra conventionnelle et biologique, afin d'analyser leurs profils environnementaux et économiques et de déterminer si la "qualité environnementale" et économique vont dans la même direction. Les méthodes employées sont le Life Cycle Assessment (LCA), réglementé par les normes de la série ISO 14040, pour l'évaluation environnementale, et le Life Cycle Costing (LCC), un nouvel instrument utilisé pour évaluer les coûts totaux (internes et externes) du système. Les résultats ont mis en évidence que le système biologique affiche une meilleure qualité environnementale par rapport au système conventionnel, mais un profil économique plus mauvais si les coûts externes ne sont pas comptabilisés.

1. Introduction

In the last ten years the Italian agricultural area cultivated in conformity with the organic method has remarkably increased, from 0.5% of the total area in 1993 to 8% in 2001. The total Italian "organic" area is about 1,200,000 ha, 15% more than the previous year, with about 60,000 farms. The "organic" area is shared among fodder (56%), wheat (18%), tree crops (19%) and vegetables (6%) (Compagnoni et al., 2001). As for the tree cropping-area (about 228,000 ha), the olive industry plays a major role, since it covers 44,175 ha. The olive oil production of the Apulia region (South Italy) covers about 50% of the total Italian production and about 18% of the EU production. In the light of these data and of the importance of the Apulian oliviculture and olive oil production (1,182 olive oil mills out of the Italian total of 5,514), a high growth rate for the organic oliviculture can be forecasted in this region. The price of virgin olive oil remains remarkably higher than that of other oils and fats even if it is characterised by a better environmental performance due to the lack of chemical treatments in the industrial stage (Nicoletti et al., 2001a).

This situation is exactly the opposite of what an environment-friendly policy should do in support of eco-compatible products on the market and is even worse in the case of the organic oil. Its price, in combination with the higher price of the typical olive oil due to the cost of olive harvesting, is higher than that of the conventional olive oil. Therefore, even more than the conventional one, organic extra-virgin olive oil is destined to be a niche product. However, we do think that a superior product from the health and nutritional point of view should be affordable by all consumers.

In this study the results of a comprehensive comparative Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) of organic and conventional extra-virgin olive oil are shown in order to:

1. assess whether the organic extra virgin olive oil is more eco-compatible than the conventional one, since different studies have shown that organic is not an a priori better alternative from the environmental point of view;
2. assess whether the higher market price of the organic oil is due to the fashionable trend of the organic products, or if it is due to effectively higher production costs.
3. identify the relative economical and environmental scores of the two systems and assess whether the dimensions converge or not in the same direction.

* Dipartimento di Scienze Geografiche e Merceologiche, Facoltà di Economia, Università di Bari, Italia

** Facoltà di Economia, Università di Foggia, Italia.

The methodology of Life Cycle Assessment (LCA), as stated by the 14040 ISO rules (ISO, 1996), is used to identify and evaluate the environmental burdens relative to the life cycle of a product, process, or activity. Moreover, it enables to convert the flows of inputs and environmental outputs, based on material and energy balances, in their relative contributions to the global or local environmental themes they are responsible for. With such information it is possible to compare alternative options in order to define the one with the best environmental quality. It is also possible to identify the "hot spots" of a system and determine the phases of the life cycle on which attention should be focused in order to minimise the emissions of certain substances.

The methodology is divided in four phases:

1. Goal and scope definition,
2. Inventory,
3. Impact Assessment,
4. Interpretation.

In the first phase, all the coordinates of the study – system boundaries, functional unit, assumptions etc. - have to be detailed in order to properly understand the system under study.

Inventory is the phase in which all the system inputs and outputs are accounted for.

In the third phase all the input and output material flows are converted into contributions to the environmental problems as, for instance, global warming potentials (expressed in kg CO^2 equivalent) or ozone depletion potentials (expressed in kg CFC-11 equivalent) etc. This phase is divided in three sub-phases: characterisation, in which the inventory flows are converted in contributions to some environmental impact categories multiplying the inventory quantities by the characterisation factors of the relative substances; normalisation, in which the impact categories scores are normalised at the macro-scale level, by dividing them by the world normalisation factors; evaluation, consisting in multiplying the factors obtained by the previous phase with a weighting factor which expresses the relative importance of the different impact categories. Eventually the factors obtained can be summed in order to obtain an eco-indicator, which is a single number expressing the environmental performance of the system.

The interpretation phase deals with the results interpretation.

Unlike LCA, whose methodology is quite well defined and standardised, the Life Cycle Cost tool is recent and so far it has had a very few applications. Basically, it shares with LCA the cradle-to-gate nature, but it is relative only to economic costs. The LCC methodology, which has been used in this paper, is that suggested by White's guidelines (White, 1996). LCC guidelines divide the costs in three categories:

1. conventional company costs,
2. less tangible, hidden and indirect costs,
3. external costs.

The first cost category is represented by the typical costs in the company accounts; consequently they are quite easy to collect, since they are basically represented by the costs of the raw materials, labour etc.

Less tangible, hidden and indirect costs are represented by some less measurable and quantifiable costs which are often obscured by placement in an overhead account; consequently their detection and collection are quite difficult especially when dealing with companies not familiar with correct environmental management practices. Examples of these costs include environmental authorizations and licensing, reporting, waste handling, storage and disposal.

External costs encompass all the social costs due to pollution, for which a company is not responsible, in the sense that neither the marketplace, nor regulations assign these costs to the firm. At the moment, these external costs are not paid by the polluter but by the polluted.

2. Organic and conventional virgin olive oil LCA

2.1 Goal and scope definition

Aim of this LCA is to compare the environmental burden of the organic and conventional virgin olive oil in order to identify the most environmentally friendly "hot spots" of the two systems and the options for their improvement.

The functional unit, which represents the quantity of the product on which the two systems are compared, is 1 kg of extra virgin olive oil. The system includes all the direct (agriculture practice, harvesting, transport and oil extraction) and indirect (production and transport of the pesticides, fuels etc.) activities, which are necessary from the field to the packaging to produce extra-virgin olive oil. The various transports of the chemicals (from the factories to the agricultural fields), of the materials and of the workers involved in the harvesting and pruning operations (from town to orchard) and of the olives (from the orchard to the oil mill) have been included in the analysis. The foreground of the two systems, represented by the orchard and the oil mill plant, is localised in the area of Andria and Corato (north-west of Bari), an area that is specialised in the production of the olive cultivar called "Coratina". The agricultural yields are about 5,000 kg/ha for the conventional olives, and 3000 kg/ha for the organic ones.

It has been assumed that the production of the organic oil takes place by using the traditional process (pressure), while that of the conventional oil by using the continuous centrifugation process. Even if the guidelines of AIAB (Italian Association of Organic Agriculture) allow using both technologies for the production of organic virgin olive oil, it has been preferred to use the traditional process since it leads to the production of oil characterised by better nutritional qualities.

The data relative to the direct activities of the two systems have been taken from agricultural farms and olive oil producers. The data of indirect activities have been taken from the scientific literature (Ribaudo, 1997; Macrae et al., 1993; A.A.V.V., 1997) and from the LCA database (Prè, 2003).

The emissions of CH_4, N_2O and NH_3 occurring during the manure stabilisation have been quantified by following Houghton methodology (Houghton et al., 1995). As in the previous notes (Nicoletti et al., 2001 a, b), the emissions of N_2O, NH_3, NO_3^-, due to the use of nitrogen fertilisers, have been assessed respectively following Bouwman, (Bouwman, 1998), ECETOC (ECETOC, 2000) and Brentrup (Brentrup, 2000) methodologies. The emissions of pesticides to air and soil during their use have been assessed following Hauschild guidelines (Hauschild, 2000), on the basis of the information taken from Muccinelli (Muccinelli, 1999).

As in the previous note (Nicoletti et al., 2000), the allocation of the inventory data between the virgin olive oil and oil husk co-products has been solved by taking into account the respective quantities produced and the respective commercial value. The husk has been assumed to go off the system, since it will be sold as raw material to olive husk oil producers. The olive mill wastewater is spread on the field as stated by the Italian regulation on this subject.

2.2 Inventory analysis

Fig. 1 reports the flowchart representing the two systems under study. In Table 1 the operations, which are necessary for the management of the organic and conventional olive orchards, are shown. Irrigation is carried out three times a year with an average yearly volume of 2-m3 water per tree.

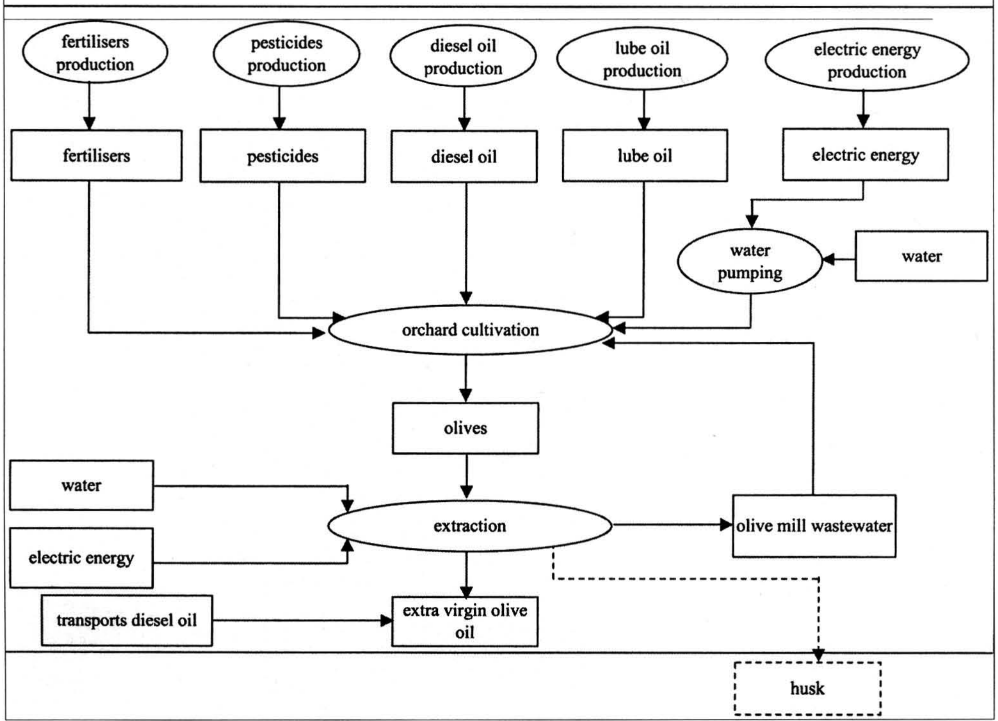
The irrigation system analysed takes the water from the water table, stores it in tanks and subsequently pumps it on the fields. These operations consume a quantity of energy equal to 1.5 kWh/m3 of water. Harvesting is carried out manually by four workers.

Pruning is carried out by four pruners plus a worker taking care of the collection and selection or incineration of the brushwood in the fields. On average the yield of a pruner is about 8-10 trees a day in orchards with about 250 olive trees per hectare, or 6 trees a day in orchards with 150 olive trees per hectare. This implies that such a team of pruners spends on average seven days for the pruning of a one-hectare olive orchard. The brushwood accounts for about 55 kg per tree. In this paper the incineration of the brushwood on the spot has been assumed after a selection of the brushwood that can be used in domestic fireplace; in both systems an alternative to this unsustainable practice consists in the pellets production or their cutting in order to enrich the soil organic matter.

In Table 2, the operations required for the cultivation of one hectare of organic and conventional olive orchards are shown together with the relative consumption of fuel; the same table shows the consumption of fuel for the movement of the productive means in every operation. The consumption of lube oil used for the agricultural equipment is 1.26 and 1.1 kg/ha respectively for organic and conventional agriculture.

In Table 3, the column "Input" reports main materials used in the agricultural phase in kg/ha. The output column reports only the main pollutants deriving from the use of fertilisers and pesticides.

Fig 1. *Flowchart of the systems under study*



The energy consumption relative to the oil extraction is different in the two technologies; it is about 0.13 kWh in the traditional system and 0.22 kWh in the continuous one per functional unit.

In Table 4, the total energy consumption of the two systems is shown.

2.3 Impact assessment

The impact assessment methodology used in this LCA is that stated by the new CML method (Guinée et al., 2002). Moreover, the category of Energy Consumption (EC) and Land Use (LU) has been added to the method. The impact categories examined are the following: Energy Consumption (EC), Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Human Toxicity Potential (HTP), Freshwater Aquatic Eco-toxicity Potential

Table 1: *Agricultural operations for the cultivation of 1 ha of organic and conventional olive orchard*

Period	Type of treatment	Product used	Quantity	
			Organic	Conventional
End of June	Pesticide spraying	Moth insecticide	2.5 kg in 1 m³ water	
End of June	Pesticide spraying	Mould and peacock's eye insecticide	5 kg in 1 m³ water	
End of June	Pesticide spraying	Olive fly insecticide	2.5 kg in 1 m³ water	
End of June	Pesticide spraying	Moth insecticide		2.5 kg in 1 m³ water
End of June	Pesticide spraying	Sooty mould insecticide		2.5 kg in 1 m³ water
End of June	Pesticide spraying	*Peacock's eye* insecticide		5 kg in 1 m³ water
End of June	Leaf fertilization	20-20-20 fertiliser		2.5 kg in 1 m³ water
End of August	Pesticide spraying	Mould and *peacock's eye* insecticide.	5 kg in 1 m³ water	
End of August	Pesticide spraying	Olive fly insecticide (fenthion)		1 kg in 1 m³ water
End of August	Pesticide spraying	Sooty mould insecticide		2.5 kg in 1 m³ water
End of August	Pesticide spraying	*Peacock's eye* insecticide		5 kg in 1 m³ water
End of August	Pesticide spraying	Olive fly insecticide (dimethoate)		1 kg in 1 m³ water
January	Pesticide spraying	Sooty mould insecticide	45 kg in 1.5 m³ water	
January	Fertilization	Fowl dung	1,000 kg	
January	Fertilization	Root fertiliser		600 kg
January	Ploughing			
March	Ploughing			
June	Ploughing			
September	Ploughing			
July-August	Irrigation	Water	500 m³	500 m³
End of November	Harvesting			
February/ March	Pruning			

(FAETP), Marine Aquatic Eco-toxicity Potential (MAETP), Terrestrial Eco-toxicity Potential (TETP), Acidification Potential (AP), Nutrification Potential (NP), Photochemical Oxidant Creation Potential (POCP) and Land Use (LU). The normalisation factors are based on the European scale and have been taken from the Dutch Directoraat-Generaal Rijkswaterstaat (Directoraat-Generaal Rijkswaterstaat, 1997). The weighting factors among the different impact categories are equal.

In Fig. 2 the results of the impact assessment phase are shown, in particular those of the characterisation. The organic system has a higher environmental burden on most of the impact categories with the exception of three toxicity categories (human, fresh aquatic, terrestrial) and of the nutrification one. The reasons of these results have to be found in the lower yield of the organic system. Obviously, this implies that in the organic system a higher surface area and a higher quantity of material and energy inputs will be necessary per functional unit, contributing more on the impact categories of land use, energy consumption, global warming, ozone depletion, acidification, photochemical smog.

In the case of the acidification category, the higher contribution of the organic system depends on the emission of ammonia during manure stabilization and the relevant emission of NOx, due to uncontrolled combustion of a higher quantity of brushwood.

As for the category of photochemical smog, the higher contribution of the organic system is again due to the lower yield which causes a higher incidence, on this system, of the environmental burdens of the uncontrolled brushwood incineration in the fields.

Regarding the categories of nutrification and toxicity the picture is completely different. In the first one, the higher incidence of the conventional system (about 20%) is due to the higher releases of nitrate and phosphate in water because of the use of triple fertilisers.

In the toxicity categories the difference between the two systems is much more evident; in the category of human toxicity the difference e-

Table 2: *Fuel consumption during the agricultural operations and transport (in kg) per ha.*

Operations	Means	Organic		Conventional	
		Agricultural operations	Transport	Agricultural operations	Transport
Ploughing	Tractor	68	4.5	68	4.5
Pesticide spraying	Tractor + tow	17	1.8	11	1.2
Manual fertilization	Tractor + tow		1.25		1.2
Harvesting	Tractor + tow	2.1	7.3	3.5	11.8
Transport of the harvester (4 units)	Car		1.75		2.8
Transport of the pruners (5 units)	Car		5		5
Pesticides transport	Truck		0.9		1.4
Fertilisers transport	Truck		63.4		38
Total		87.1	85.9	82.5	65.9

Tab. 3. *Inputs and main outputs of the sgricultural stage (kg/ha)*

Inputs	Organic	Conventional
Water (m^3)	505.5	508
Electrical energy (kWh)	750	750
Pesticides		
Active ingredient		
Methidathion		0.47
Carbaryl		2.37
Copper (as oxychloride)		3
Copper (as $CuSO_4$)	2.5	
Fenthion		0.48
Dimethoate		0.38
Organic insecticide	5	
Hydrated lime	45	
Fertilizers		
Fertilizer (20-20-20)		2.5
Fertilizer (15-5-5)		600
Organic manure (2-3-1,6)	1,000	
Outputs		
Emissions to air		
NH_3	4.28	1.81
N_2O	0.24	1.13
Dimethoate		0.20
Fenthion		0.07
Carbaryl		0.49
Methidathion		0.06
Emissions to water		
Phosphate	0.9	0.92
Nitrate	15.3	39.6
Emissions to soil		
Dimethoate		0.11
Fenthion		0.24
Carbaryl		1.19
Methidathion		0.24
Cu	0.06	0.12

quals 15%, while it is enormous in the fresh aquatic and terrestrial toxicity. In the human toxicity the difference is limited because the toxicity of the pesticides used in the conventional system is counterbalanced by the toxic emissions relative to the higher energy consumption of the organic system. This counterbalance does not happen in the fresh aquatic and terrestrial toxicity because both the quantities and the toxicity factors for the pesticides in fresh water and on land are very high. On the contrary, the marine toxicity is higher in the organic system because of its higher energy content and because in the conventional system there is a small fraction of pesticides flowing into the sea.

Going through the normalisation and evaluation stage, Fig. 3 reports the incidence of each life cycle stage on the eco-indicators of the two systems. The life cycle has been divided in four phases: raw materials procurement, olives production (agricultural stage), oil production (industrial stage), and transports. In the conventional system the most burdening phase is represented by the agricultural one mainly due to the use of pesticides and fertilisers, followed by the raw materials procurement, transports and oil extraction. On the other hand, in the organic system, the raw materials procurement (the sum of all the phases necessary for electricity production, fuels, pesticides and fertilisers supply etc) has a slightly higher impact compared to the agricultural phase, whose impact is much lower than the conventional system due to the lack of synthetic fertilisers and pesticides. The impact categories more involved are POCP, MAETP, AP and NP for the organic system and FAETP, TETP, MAETP and NP for the conventional one.

Tab. 5. *Internal and external costs of the two systems for functional unit ( )*

Agricultural phase	Organic	Conventional
Pesticides	0.171	0.117
Fertilisers	0.268	0.181
Lube oil	0.023	0.011
Electrical energy	0.143	0.085
Water	0.077	0.046
Diesel	0.084	0.048
Labour	4.344	2.864
Organic certification costs	0.064	
Total	5.174	3.352
Transports	0.0784	0.039
Industrial phase		
Electrical energy	0.014	0.024
Labour	0.089	0.045
Water	0.002	0.022
Packaging	0.298	0.298
Waste authority	0.015	0.015
Organic certification costs	0.009	
HACCP certification costs	0.0009	0.0009
Total	0.428	0.405
	5.680	3.796
External costs of energy	0.664	0.533
External costs of fertilisers and pesticides	0.439	9.870

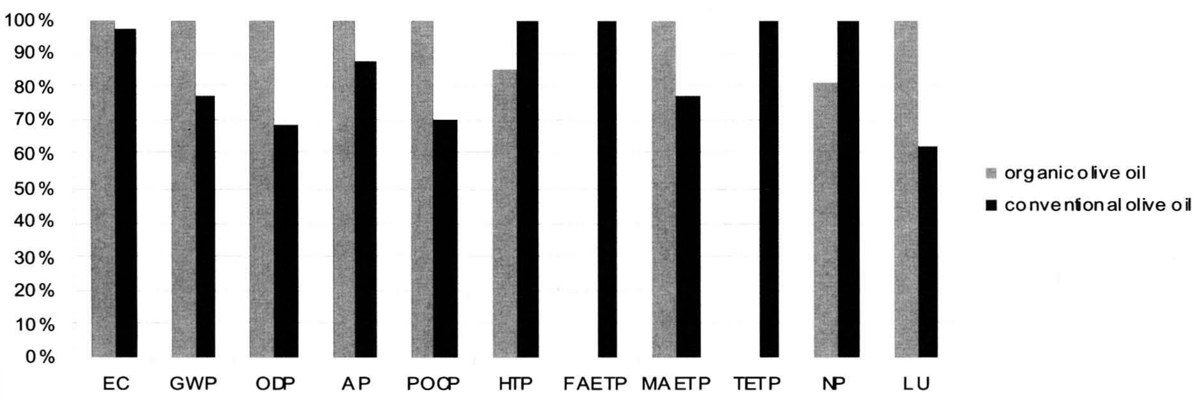
Table 4: *Total energy consumption in the two systems*

	Organic				Conventional			
	Diesel oil		Electrical energy		Diesel oil		Electrical energy	
	kg	MJ	kWh	MJ	kg	MJ	kWh	MJ
Agricultural operations	0.151	6.4	0.13	1.2	0.086	3.6	0.08	0.8
Industrial transformation			0.13	1.2			0.22	2.0
Transports	0.160	6.7			0.080	3.4		
Total	0.311	13.1	0.26	2.4	0.166	7.0	0.30	2.8
Total consumption (MJ)	15.5				9.8			

2.4 Interpretation

Fig. 2 shows that the organic system has higher burdens on all the impact categories but, by further aggregating the eleven impact categories in a single eco-indicator, the organic system results to

Fig. 2. *LCA results – characterisation*



The study has taken into account the impact of the agricultural activities on the groundwater and has assessed this impact showing that the damage caused by conventional agriculture due to fertilisers and pesticides in terms of reclamation and decontamination costs is 33 times higher than that of organic agriculture.

be 5 times more eco-compatible than the conventional one because of the high burden of the conventional system in the agricultural phase due to the relevant impact of the pesticides.

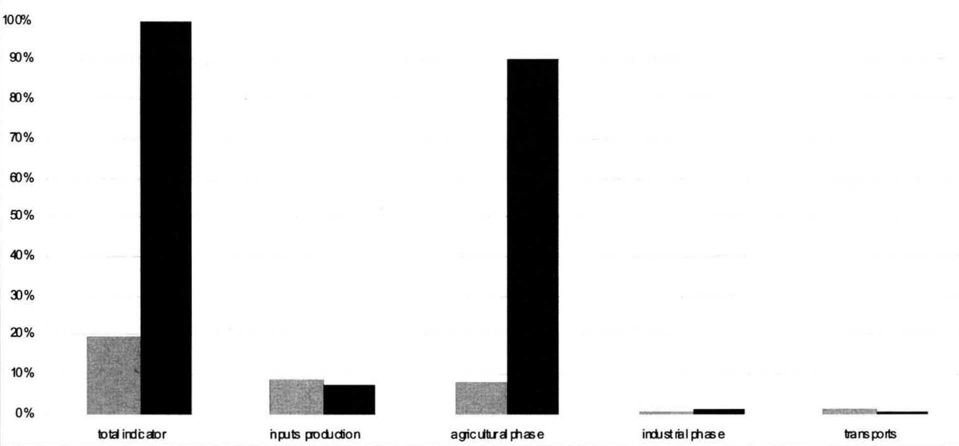
An important option for the improvement in both systems could be the abandonment of the brushwood incineration in the fields that could lead to a relevant reduction of the impact both on the category of photochemical smog and on that of human toxicity.

Options for improvement in the conventional system are to be found in a more rational use of pesticides, while an interesting improvement in the organic system could be the abatement of the ammonia emission during the stabilization of the manure; this implies that the manure stabilization should take place not in the fields but in closed sheds.

3. Organic and conventional virgin olive oil LCC

The internal and external costs are shown in Table 5. The external costs relative to the energy have been taken from the ExternE National Implementation Italian Report (ExternE, 1997), while those relative to the use of pesticides and fertilisers from a study of the University Bocconi, (Milan, Italy) in which the production and social costs of the organic and conventional agriculture have been compared.

Fig 3. *LCA results – evaluation*



4. Conclusions

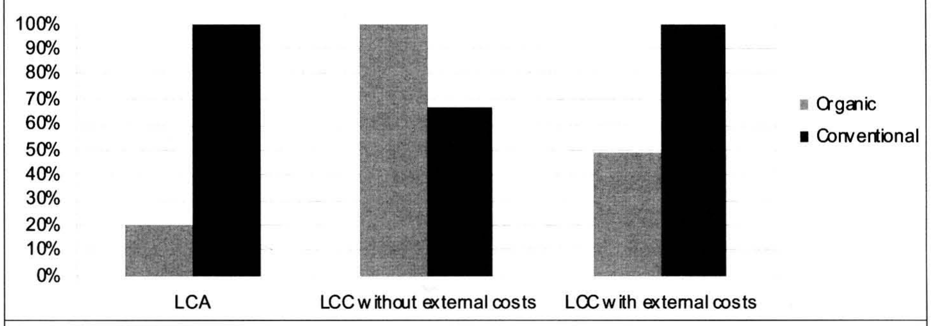
Similarly to other studies on the organic systems (Nicoletti et al., 2001 b), the results of LCA show that the organic system scores worse than the conventional one in all the impact categories with the exception of NP, HTP, TETP and FAETP. The lower yield of the organic system is the reason of this result. By going through the evaluation step (Fig. 4), it can be found out that the organic system is more eco-compatible than the conventional one of about 5 times due to the relevant difference in the TETP and FAETP impact categories.

On the cost side, Table 5 has shown that the organic system is characterised by higher production costs due to the organic lower yields. These higher costs are reflected in a higher market price.

Figure 4 shows the differences in the results based on the external costs. If external costs are not considered, the organic oil has a higher cost profile; on the contrary, by adding the external costs, which are not actually paid by the farmer and by the olive oil companies, to the conventional company costs and to the less tangible, hidden and indirect company costs, it can be found out that the organic oil has a lower total cost compared to the conventional oil. This result enlightens the need to account for external costs as the European Commission has started to do (Labouze et al., 2003).

The options for environmental improvement in the conventional system are mainly related to a more reasonable use of pesticides while, in the case of the organic, a reuse of the brushwood as fuel, rather than its uncontrolled burning in the field, could lead to a better environmental profile both in HT and in POCP. Moreover, in the organic system the "traditional" extraction method has been used in the inventory set-up; on the contrary, the AIAB guidelines (AIAB, 2001) enable the organic oil producer to use the "continuous-extraction method" which is characterised by energy consumption double than the traditional process. These guidelines should pay more attention to the energy consumption, since the consumer who is interested in organic foods wants to buy a more eco-compatible product, which is characterised not only by the absence of chemical fertilisers and pesticides but also by the least energy consumption.

Fig. 4. *LCA-LCC without external costs and with external costs*



On the costs side, Fig. 4 has shown the importance of taking into account the external costs. Since a lower cost of the organic olive oil compared to the conventional one is not obtainable on the market place just with the "market laws", it is necessary to promote governmental policies which could reduce the gap between the cost of the conventional oil calculated by the traditional cost accounting methods and those calculated by following the LCC approach. The aim should be that on the basis of the same quality standards, products with a better environmental profile should have a lower market price compared to the competitor; exactly the contrary of the present situation in which the most eco-compatible products have higher market prices.

Acknowledgments

The authors thank the olive oil farm "Polvere delle Rose", Corato, and the farmer Mr. Gaetano Di Bisceglie for their precious collaboration.

References

A.A.V.V., 1997. Agricultural Handbook, II edition, Editor Hoepli, Milan (in Italian).

AIAB (Associazione Italiana Agricoltura Biologica), 2001. Protocol for the production of extra virgin olive oil. (In Italian). Downloadable at www.aiab.it

Bouwman A.F., 1998. Compilation of a global inventory of emissions of Nitrous Oxide. Ph.D. thesis, University of Wageningen, the Netherlands.

Brentrup F., Küsters J., Lammel J., Kuhlmann H., 2000. Methods to estimate on-field nitrogen emission from crop production as an input to LCA studies in the agricultural sector. The International Journal of LCA 5 (6), 349-357.

Compagnoni A., Pinton R., Zanoli R., 2001. Organic farming in Italy 2001, www.organic-europe.net

Directoraat-Generaal Rijkswaterstaat, 1997. Drie referentieniveaus voor normalisatie in LCA The Netherlands, 1997.

ECETOC, 2000. Ammonia emissions to air in Western Europe. Technical report no. 62. European Chemical Industry Ecology & Toxicology Centre, Brussels, Belgium.

ExternE National Implementation Italy. Final Report. October 1997. Downloadable at http://externe.jrc.es/it.pdf

Guinèe J.B., Gorèe M., Heijungs R., Huppes G., Kleijn R., Koning A. de, Oers L. van, Wegener Sleeswijk A., Suh S., Udo de Haes H.A., Bruijn H. de, Duin R. van, Huijbregts M.A.J., 2002. Handbook on Life Cycle Assessment, Operational Guide to ISO Standards, Kluwer Academic Publishers, Dordrecht.

Hauschild M., 2000. Estimating pesticide emission for LCA of agricultural products. In B. P. Weidema, M.J.C. Meeusen (ed.): Agricultural data for Life Cycle Assessment. II vol., 64-79, Agricultural Economics Research Institute, The Hague.

Houghton J.T., Meira Filho L.G., Callander B.A., Harris N., Kattenberg A., Maskell K., 1995. Climate Change 1995. The Science of climate change; contribution of WGI to the second assessment report of the intergovernmental panel on climate change, Cambridge University Press, Cambridge.

International Organization for Standardization ISO/DIS 14040, 1996. Environmental management - Life cycle assessment - Principles and framework, ISO/TC207/SC5.

Labouze E., Monier V., Le Guern Y., 2003. Study on external environmental effects related to the life cycle of products and services, European Commission, Directorate General Environment.

Macrae R., Robinson R.K., Sadler M.J, 1993. Encyclopedia of Food Science Food Technology and Nutrition, Academic Press Limited, London.

Muccinelli M., 1999. Pesticides handbook, VIII ed., Edagricole, Bologna, (in Italian).

Nicoletti G.M., Notarnicola B., Tassielli G., 2001. Comparative LCA of virgin olive oil vs. seed oil. In Proceedings of the International Conference LCA in Foods, 26-27 April, 2001, Gothenburg, Sweden.

Nicoletti G.M., Notarnicola B., Tassielli G., 2001. Comparison of conventional and organic wine. In Proceedings of the International Conference LCA in Foods, 26-27 April, 2001, Gothenburg, Sweden.

Nicoletti G.M., Notarnicola B., 2000. The environmental impact of the olive oil: agricultural and extraction techniques. In Proceedings of the XIX National Symposium of Commodities Science, Sassari, 27-29 September 2000, II volume, 243-252, (in Italian).

Prè Consultant, 2003. Simapro 5, Amersfoort, the Netherlands.

Ribaudo F., 1997. Handbook of Agriculture, Edagricole, Bologna, (in Italian).

White A.L., Savage D., Shapiro K., 1996. Life Cycle Costing: concept and applications. In Curran M.A. (eds.), Environmental Life Cycle Assessment, Mc Graw Hill, New York.