Olive Oil Production Chain

Original Citation:

Olive Oil Production Chain / P. Boncinelli; L. Recchia; E. Cini. - ELETTRONICO. - (2011), pp. 99-128. [10.1007/978-0-85729-704-4_5]

Publisher:
Springer

Published version:
DOI: 10.1007/978-0-85729-704-4_5

Chapter 5
Olive Oil Production Chain

5.1 Introduction

In Chap. 3, the energetic reuse of agricultural residues coming from olive oil production chain is investigated exploiting both Multicriteria Analysis (MCA) and Life Cycle Assessment (LCA) methodologies. In this Chapter, attention is focused on other aspects of the olive oil working chain: olive grove characteristics, management and productivity; olive harvesting and transport to the extraction plant; olive oil extraction process.

The reference framework for this study is, again, Italy and, in particular, Tuscany. Over the last decades the role of Tuscan agriculture and, consequently that of farms has slowly changed. Originally, farms were only considered as technical-economic units where agricultural, forestry or zootechnical productions were implemented. Nowadays, new tasks have been added to traditional ones: landscape conservation, land coverage and environmental protection by various types of pollution. These tasks are associated with farms not only by national and European policies, but also by market requirements. Actually, Tuscany is characterized by high-quality agricultural products, whose alimentary function is usually joined to the culture of the specific territory in which they are produced. As a consequence, Tuscan agriculture, in particular high-quality products, mostly refers to high-level markets, which are interested in both food product quality and its associated cultural message. For these reasons, recent regional planning policies in agriculture have strongly promoted technological innovations in production processes aimed at both preserving landscape and environment and, at the same time, improving product quality.

Extra-virgin olive oil represents, together with wine, the most typical agricultural product characterizing Tuscany in both national and international markets. Olive grove landscapes and high-quality oil are worldwide associated with the idea of Tuscany. However, in the last decades, economic sustainability of olive oil production chain has become critical, due to several factors: fragmentation of the

L. Recchia et al., *Multicriteria Analysis and LCA Techniques*,
Green Energy and Technology, DOI: 10.1007/978-0-85729-704-4_5,

production web, increasing labour cost, difficulties in grove management due to territory peculiarities, increasing national and international competition. Additional efforts are required to apply a philosophy of "total quality", where quality means optimization of all resources required by the production process, which, at the same time, should provide one with essential information for performing strategic planning, as extensively discussed in Chap. 1. As a consequence, developing adequate methodologies to quantify and evaluate environmental sustainability associated with olive oil production chain is essential, considering also the possibility of settling environmental certifications as an additional value to product quality.

In this prospect, recent studies [2–4, 8] have shown how both MCA and LCA methodologies can represent effective tools to analyse olive oil production chain. This can be achieved not without any difficulty, due to the extreme heterogeneity of agricultural processes associated with the variety of environments in which crops grow, to the different typologies of cultivars of each crop, to the various levels of mechanization in field, to the residues management, and so on. In this chapter, an example of the application of these methodologies is provided.

5.2 Multicriteria Analysis to Define and Optimize the Olive Oil Chain

According to the general scheme discussed in Chap. 2, the analysis of the olive oil chain starts from the definition of different possible scenarios concerning the different phases of the chain, that is:

1. Agricultural phase (olive grove typology, fertilization and weed control, olive harvesting and prunings reuse);
2. Olive transport from the grove to the olive oil mill (logistics);
3. Extraction phase (configuration and size of the extraction plant, machine typology, and waste reuse).

Different scenarios can be combined in order to define the whole olive oil production chain. However, as discussed in Chap. 2, the possible scenarios are characterized by a large variability. The application of the MCA methodology is useful to help one in selecting the most significant scenarios according to the following essential requirements which must be set in advance:

- Main goals that must be accomplished;
- Main benefits and drawbacks associated with each scenario;
- A number of evaluation criteria for scenario selection;
- Outcomes and/or scores associated with each scenario for each evaluation criterion.

Scenarios that achieve higher scores represent the most suitable combinations according to the imposed requirements. They are subsequently considered for further evaluation by means of a LCA analysis.

5.2.1 Scenarios Definition

Scenarios for the olive oil production line are defined considering different solutions available for the olive grove, transport from the grove to the mill and the extraction plant. Details of the selection are reported here.

For what concerns the agricultural phase, olive grove configurations are identified taking into account models that can be adapted to the reference territory for which the analysis is performed. In the present application, which refers to the Tuscan territory and agriculture, four different grove models are defined according to Cresti et al. [7]:

1. Marginal olive groves (Fig. 5.1a, b), characterized by severe structural constraints: irregularly shaped trees aged 50 years or more; steeply sloped (over 25%) or terraced grounds located in hill and mountain areas hardly accessible by mechanical devices and requiring high work levels both for maintenance (pruning, scrub control, wall and terrace repairings) and for harvest; highly variable and irregular tree distribution over small areas (usually less than 5 ha);
2. Traditional olive groves (Fig. 5.1c, d), characterized by trees aged between 25 and 50 years distributed over middle-sloped grounds (between 10 and 25%) located in hills and/or rolling plains, easily accessible by most mechanical devices for agricultural operations; typical field size is around 5 ha, with an average tree density of about 250 trees/ha;
3. Intensive olive groves (Fig. 5.2a), characterized by young, regularly shaped plants (aged less than 25 years) distributed over rolling or flat plains sloped less than 10%, where most agricultural operations (both for grove management and for harvest) are mechanized; high tree density (up to 500 trees/ha);
4. Super-intensive olive groves (Fig. 5.2b), which differ from intensive ones mainly for tree density (up to 1,000 trees/ha) and fully mechanized management and harvest; their diffusion, even if still limited in Tuscany, has been increasing in the last few years. Details of the four field scenarios are summarized in Table 5.1.

Collected olives must be carried from the grove to the mill for olive oil extraction within 24 h from harvest, in order to preserve olives from degenerative processes and increase oil quality. As a consequence, olive transport represents a critical step in the whole production chain of high quality extra-virgin oil. Different solutions are possible, depending on the location of olive groves, and the size and typology of olive mills. However, considering the Tuscan situation characterized by small—sized farms spread all over the country, it is common to have olive mills located inside each farm, or at a short distance (usually less than

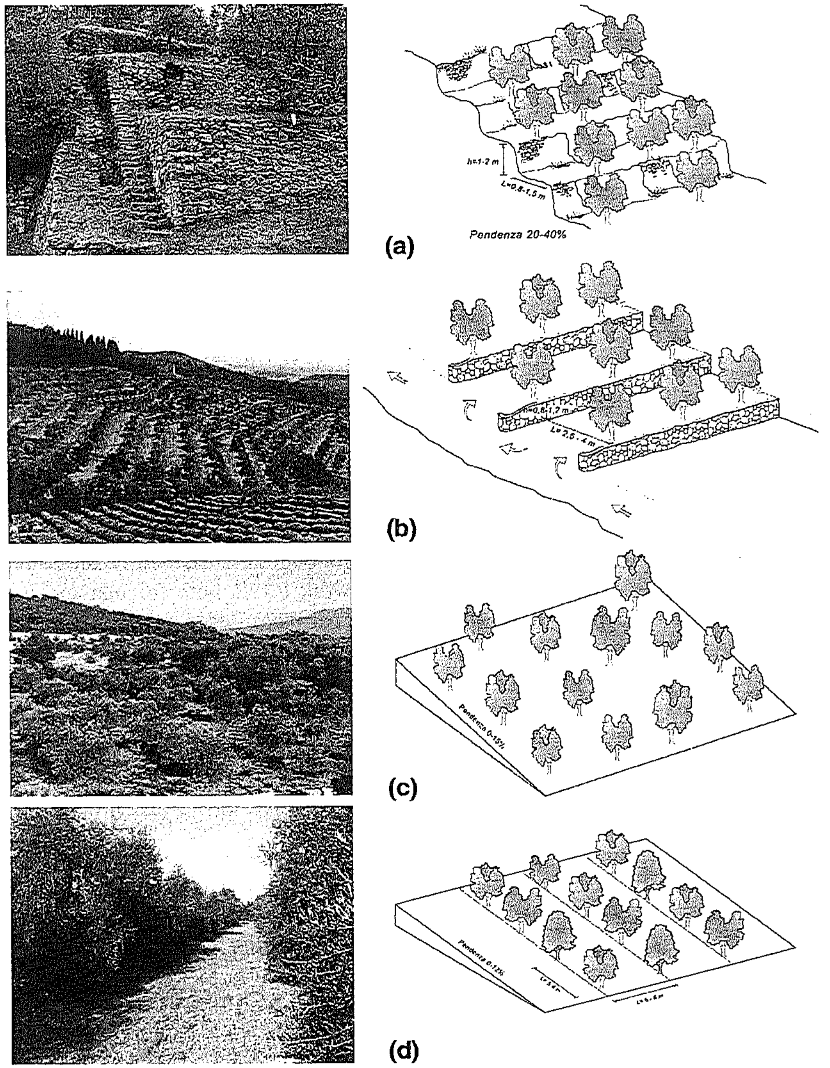


Fig. 5.1 Marginal and traditional olive grove models (from Cresti et al. [7]). **a** Non accessible marginal olive grove (F1 scenario), **b** accessible marginal grove (F1 scenario), **c** irregular traditional grove (F2 scenario), **d** regular traditional grove (F2 scenario)

10 km) from it. Recently, a number of large-sized cooperative mills have been developing, which collect and process olives from wider areas. For these reasons, three different scenarios for olive transport have been identified and considered for the present analysis:

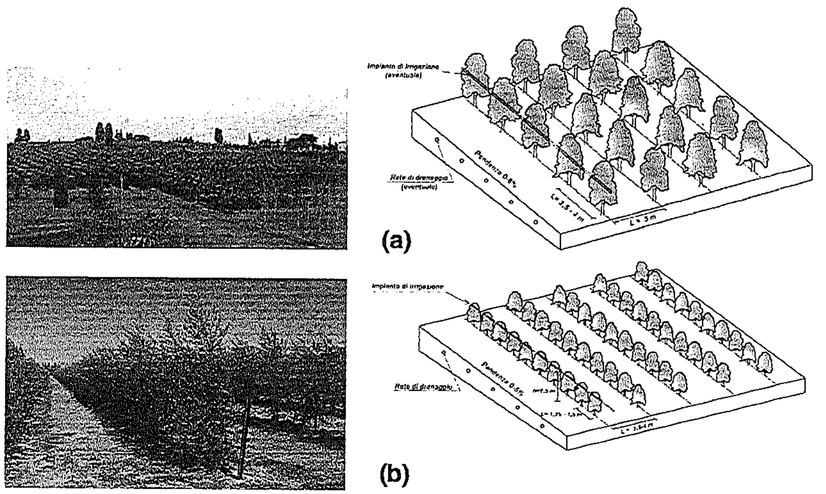


Fig. 5.2 Intensive and superintensive olive grove models (from Cresti et al. [7]). **a** Intensive grove (F3 scenario), **b** superintensive grove (F4 scenario)

1. No transport: olives are processed inside each farm in the local olive mill;
2. Short-distance transport: olives are processed in olive mills located within 10 km from the grove;
3. Medium-distance transport: olives are processed in olive mills at a distance between 10 and 50 km from the grove.

In the first scenario, olives are carried to the mill by the same devices used for field management (mainly farm tractors, Fig. 5.3). Pick-up vans are used in the second scenario, allowed by the short distance between the farm and the mill, and the limited amount of olives typically transported (300–1,000 kg of olives for each lot). For longer distances and larger loads, as those typical of the third scenario, lorries are usually employed. Details of the three transport scenarios are reported in Table 5.2.

Oil extraction is the third phase of the production chain. In the last decades, centrifugal decanters have become widely employed to separate oil from vegetation water and pomace, so the basic layout of modern extraction plants is quite similar for most olive oil mills:

1. Olive defoliation and washing (Fig. 5.4);
2. Olive milling (Fig. 5.5);
3. Kneading (Fig. 5.6);
4. Centrifugal separation (decanter) (Fig. 5.7);
5. Filtration (Fig. 5.8).

However, within this basic layout, different solutions are possible. The use of different milling machines (hammer, stone or disc mills), horizontal or vertical

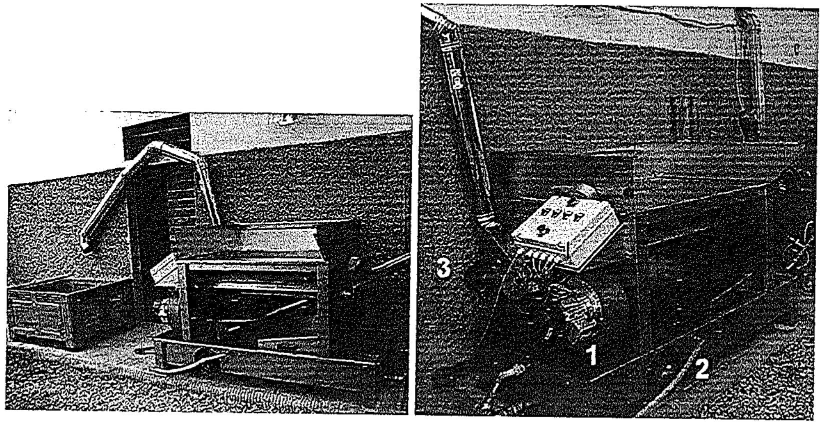
Table 5.1 Definition of olive grove scenarios (data from Cresti et al. [7] and EFNCP/ARPA [9])

Grove model	Scenario	Field characteristics	Field management and mechanization
Marginal	*F1*	Irregularly shaped trees sometimes in mixed orchards	No fertilization
		Tree age range: ≥50 years	No irrigation
		Steeply sloped (>25%)/ terraced grounds with walls	No/occasional pesticide use (copper)
		Typical location: hill and mountain areas	No mechanization
		Typical field size: ≤5 ha	No prunings reuse
		High variable tree density	
Traditional	*F2*	Irregularly distributed trees	Organic fertilization (animal manure, leaves, compost, manufactured organic fertilizers)
		Tree age range: 25–50 years	No irrigation
		Middle-sloped (10–25%) grounds	Pesticide use: 2–10 treatments per year
		Typical location: hills and rolling plains	Partly mechanized prunings collection, by-hand harvesting with vibrating poles
		Typical field size: 5–10 ha	No prunings reuse
		Tree density: ≤250 trees/ ha	
Intensive	*F3*	Regularly arranged orchards short, with single-stem trees	Mineral fertilization
		Tree age range: ≤25 years	Drip-system irrigation
		Little-sloped (≤10%)/flat grounds	Pesticide use: 2–10 treatments per year
		Typical location: rolling/ flat plains	Mechanized prunings collection and harvesting
		Typical field size: ≥10 ha	Energetic reuse of prunings
		Tree density: 250–500 trees/ha	
Superintensive	*F4*	Regularly arranged orchards short, with single–stem trees	Mineral fertilization
		Tree age range: ≤25 years	Drip–system irrigation with pumping plant
		Little-sloped (≤10%)/flat grounds	Pesticide use: 2–10 treatments per year
		Typical location: flat plains	Fully mechanized agricultural operations
		Typical field size:≥10 ha	Energetic reuse of prunings
		Tree density: 500–1,000 trees/ha and more	

Fig. 5.3 Olives conferred to the mill by means of a farm tractor (*T1* scenario)

Table 5.2 Definition of transport scenarios

Transport	Scenario	Distance	Notes
Local	*T1*	No transport (local mill inside farm)	Olive management operated by farm tractors
Short distance	*T2*	≤10 km	Operated by pick-up vans
Medium distance	*T3*	10–50 km	Operated by lorries



(a) (b)

Fig. 5.4 Olive defoliation and washing machine. **a** Overall view, **b** *1* hopper engine for olive feeding; *2* water pump; *3* fan for foliage discharge

kneading, two- or three-phase centrifugal decanters for oil separation, has a significant impact on both mill management and olive oil characteristics. Moreover, waste treatment (vegetation water and pomace) represents another critical point in the extraction phase, especially for what concerns economic and environmental sustainability of the whole process.

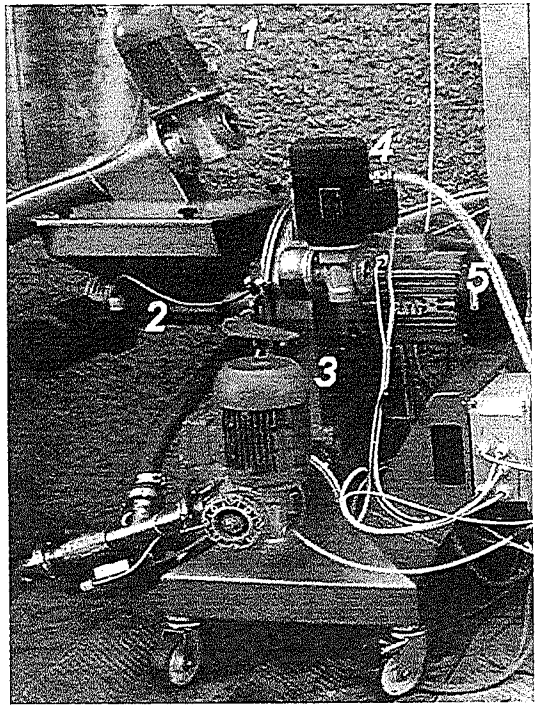


Fig. 5.5 Olive milling machine: *1* Olive feeding pump, *2* milling hopper, *3* milling engine, *4* cleaning grid engine, *5* kneading machine feeding pump

In the present analysis three different mill scenarios are taken into account, referring to typical situations found in Tuscany:

1. A small-sized traditional olive mill, located inside the farm, characterized by a small working capacity (less than $\leq 200\ \mathrm{kg_{olives}/h}$), essential technology with a two-phase decanter, no waste reuse with both vegetation water and pomace delivered in field, using natural gas (methane) for both plant heating and sanitary water production (*P*1 scenario);
2. A medium-sized olive mill, which can serve several farms located at a short distance, characterized by a working capacity between 200 and 500 $\mathrm{kg_{olives}/h}$ with a two-phase decanter, no waste reuse with both vegetation water and pomace delivered in field, but exploiting prunings as biofuel used in the heat boiler (*P*2 scenario);
3. A medium-sized olive mill, similar to the previous one, but equipped with a pomace stone separator (Fig. 5.9), in order to exploit both pomace stone and prunings as biofuels (*P*3 scenario).

The characteristics of each scenario are summarized in Table 5.3. For what concerns *P*3 scenario, thermal energy for both plant heating and sanitary water is supposed to be provided by a wood chips boiler burning prunings only. This solution allows one to avoid using boilers burning different kinds of biofuels, which usually require a more complex management, with different regulations for each kind of biofuel, have a lower efficiency and a more expensive maintenance.

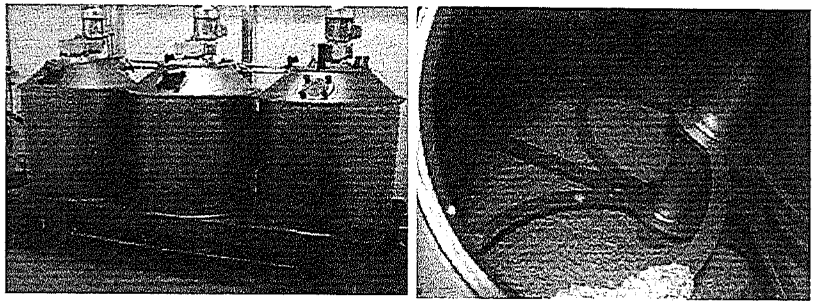


Fig. 5.6 Vertical kneading machines

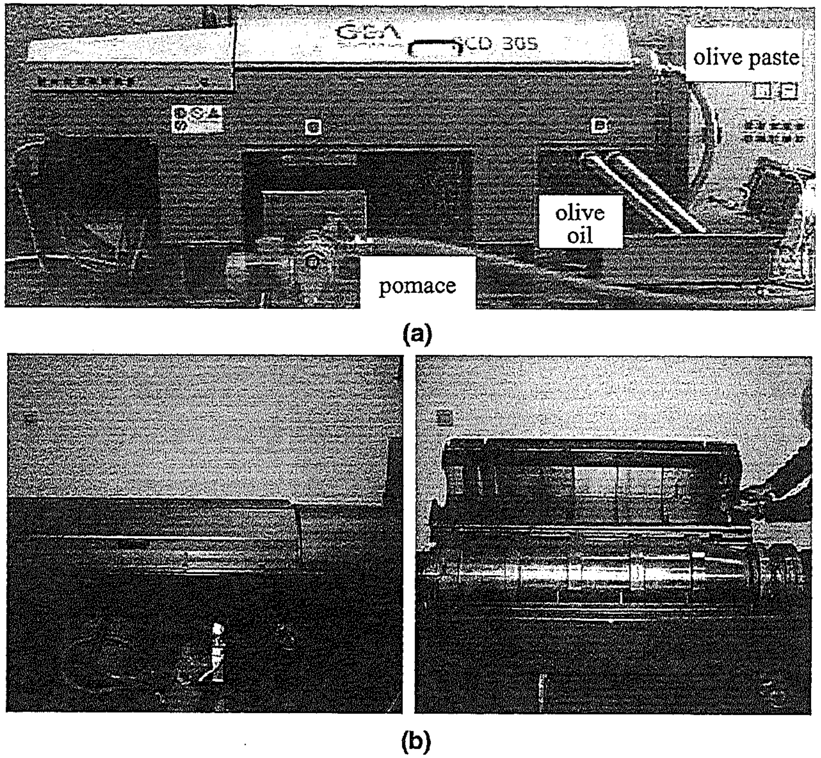
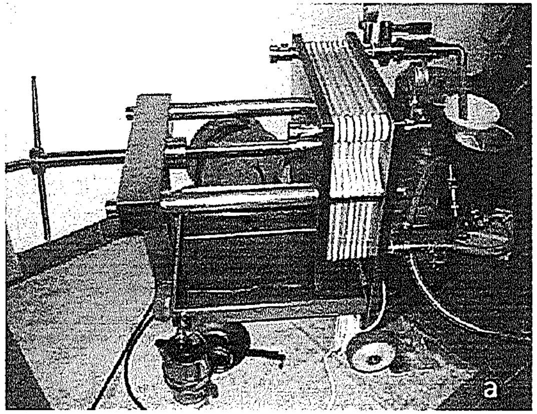


Fig. 5.7 Two-phase centrifugal decanter. **a** Overall external view, **b** internal view

Fig. 5.8 Paper filter



Stone extracted from pomace can be sold, representing an additional income source for the mill, and, at the same time, having beneficial environmental effects, since it can replace the use of natural gas elsewhere.

5.2.2 Evaluation Criteria Identification

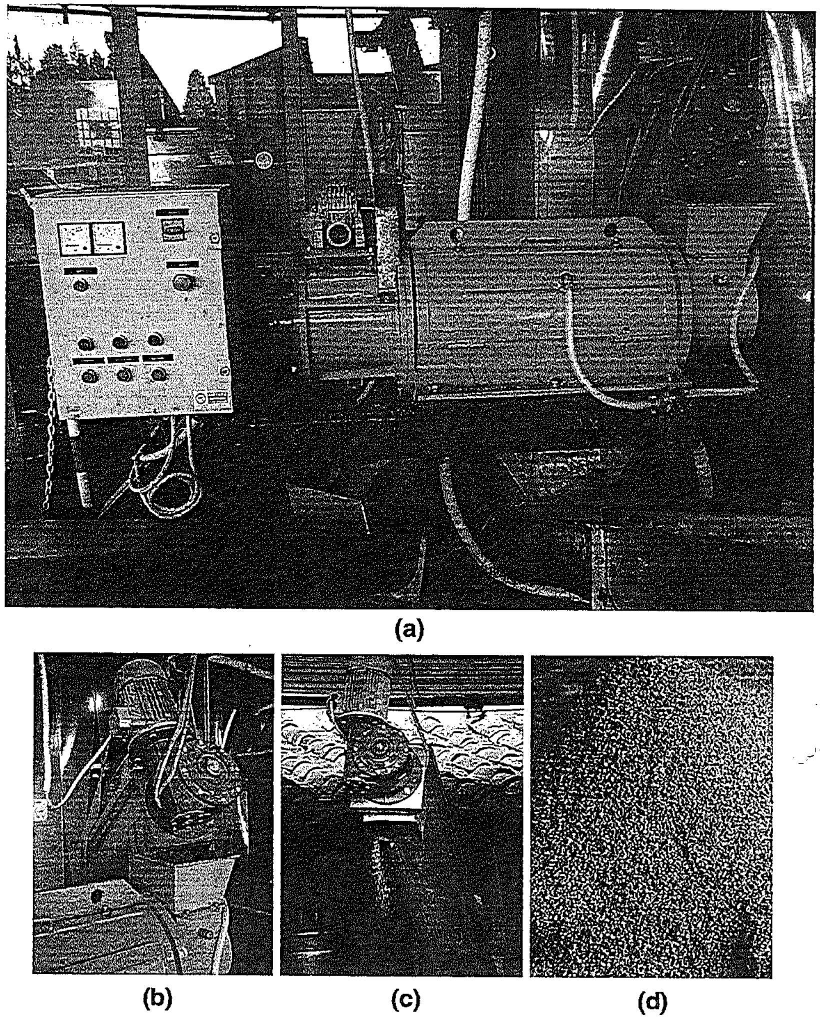
For each scenario illustrated in Sect. 5.2.1 a number of evaluation criteria concerning both environmental impacts and economic sustainability are defined, in order to quantify and compare different benefits originating from each scenario. This allows one to associate a score to each scenario, which takes into account both environmental and economic aspects related to it.

Evaluation criteria are set according to the following rules:

1. From the environmental point of view, the most favourable scenarios are characterized by low mechanization levels of field management, short transport distances and high-efficient extraction plants exploiting energetic reuse of field and plant wastes (prunings and/or pomace stone);
2. For what concerns economic aspects, both field and plant management costs are considered, as well as the whole chain productivity.

Scores associated with each scenario can be determined in different ways, depending on the examined application and the decision maker choice. Here, two methods are considered:

1. By assigning a qualitative score (*A*, *B*, *C*, …) to different scenarios, from the most to the less favourable one, and combining them by means of a decision–ranking matrix [12];
2. By using numerical scores, the higher one corresponding to the most favourable scenario, and averaging them on the number of criteria for both environmental and economic aspects.


(a)

(b) (c) (d)

Fig. 5.9 Pomace stone separator. **a** Overview of stone separator, **b** pomace feeding pump, **c** stone output, **d** extracted pomace stone

Three different qualitative scores have been adopted here (*A*, *B*, *C*), corresponding to numerical scores ranging from 3 to 1. Details of adopted evaluation criteria and their corresponding scores are reported in Table 5.4. These criteria have been chosen considering the scenarios taken into account in the present analysis (Tables 5.1, 5.2, 5.3), and exploiting data reported in the literature.

Table 5.3 Definition of extraction plant scenarios

Plant model	Scenario	Plant characteristics
Small-sized	*P*1	Working capacity: ≤200 kg_{olives}/h Two-phase decanter No pomace stone separation By-products (pomace and vegetation water) treated as waste Heat boiler with natural gas as fuel
Medium-sized	*P*2	Working capacity: 200–500 kg_{olives}/ h Two-phase decanter No pomace stone separation By-products (pomace and vegetation water) treated as waste Heat boiler with olive prunings as biofuel
Medium-sized with pomace stone separation	*P*3	Working capacity: 200–500 kg_{olives}/h Two-phase decanter Pomace stone separation Pomace residue and vegetation water treated as waste Heat boiler with olive prunings and pomace stone as biofuel

Table 5.4 Definition of evaluation criteria for olive oil chain scenarios

Criteria	Description	Scenario typology	Weights		
			A = 3	*B* = 2	*C* = 1
Environmental aspects					
*CA*1	Irrigation	*F*	No irrigation	Without pumping plant	With pumping plant
*CA*2	Fertilization	*F*	No fertilization	Organic fertilizers	Mineral fertilizers
*CA*3	Harvest method	*F*	Manual	Partly mechanized (vibrating poles)	Fully mechanized
*CA*4	Transport distance	*T*	No transport (local olive mill)	≤10 km	>10 km
*CA*5	Waste reuse	*P*	Prunings and pomace stone	Prunings	No reuse
Economic aspects					
*CE*1	Olive harvest costs	*F*	≤50 €/q	50–70 €/q	≥70 €/q
*CE*2	Prunings management costs	*F*	≤70 €/t	70–110 €/t	≥110 €/*t*
*CE*3	Olive yield	*F*	≥6 t/ha	4–6 t/ha	≤4 t/ha

Environmental aspects divide traditional, low-mechanized olive groves from intensive, highly mechanized ones, which reuse both field and extraction plant wastes as sources of renewable energy, while reducing the amount of fossil fuels employed in the production process.

For what concerns the economic aspects, numerical values for the selected criteria have been chosen referring to existing databases. In particular, values for each field scenario are determined as follows.

5.2.2.1 Olive Harvest Costs and Olive Yield

Harvest costs depend on several factors: tree distribution and density in the grove, average olive yield for each tree, harvest method (manual or mechanized). Cresti et al. [7] provide a detailed discussion about harvest cost evaluation for different olive grove typologies, reporting harvest costs by hectare of field and by quintal of olives as a function of the harvest method. Here, the following assumptions for each scenario are made:

*F*1 scenario: small field size (≤5 ha) with ancient trees characterized by a very large canopy, producing more than 20 kg_{olives}/tree; manual harvest with 10 workers; global harvest cost: 80 €/q_{olives} [7]; maximum olive yield: 1.5 t/ha [9];

*F*2 scenario: field size 5 ha with old trees characterized by a large regular canopy, producing 20 kg_{olives}/tree; tree density 250 trees/ha; partially mechanized harvest (vibrating poles) with 10 workers; global harvest cost: 70 €/q_{olives} [7]; olive yield: 5 t/ha [9];

*F*3 scenario: field size 10 ha with uniformly-distributed trees characterized by a regularly pruned canopy, producing 10 kg_{olives}/tree; tree density 500 trees/ha; fully mechanized harvest (olive shaker and gathering umbrella); global harvest cost: 40 €/q_{olives} [7]; olive yield: 5 t/ha [9];

*F*4 scenario: field size 20 ha with young, uniformly-distributed trees characterized by a regularly pruned canopy, producing 8 kg_{olives}/tree; tree density 800 trees/ha; fully mechanized harvest (olive shaker and gathering umbrella); global harvest cost: 35 €/q_{olives} [7]; olive yield: 6.4 t/ha [9].

5.2.2.2 Prunings Management Costs

Prunings management in olive groves is analysed and discussed in detail in Chap. 3. Here, some data are considered in order to provide a rough estimation of its economic impact on the whole production chain, referring to the examined four field scenarios and considering an average prunings production of about 3 t_{wb}/(ha year):

*F*1 scenario: prunings are collected, piled up and and burned in field by hand, requiring a considerable amount of manpower. Considering a manpower

Table 5.5 Decision ranking matrix adopted for criteria scores combination

	A	B	C
A	*A*	*A*	*B*
B	*A*	*B*	*C*
C	*B*	*C*	*C*

cost of 12 €/h and a productivity of 0.18 t/h both for prunings collection and piling and for prunings burning [7], the estimated overall cost amount exceeds 130 €/t;

*F*2 scenario: prunings are collected by hand, piled up together by means of a tractor equipped with forks, and manually burned in field. For this case, considering the same values for manpower unitary cost ad productivity as for the *F*1 scenario, and a cost of about 50 €/h with a productivity of 1 t/h for the tractor (see Cresti et al. [7] and Chap. 3), the estimated overall cost amount is about 100 €/t;

*F*3 and *F*4 scenarios: both scenarios assume a fully mechanized prunings management with prunings reused as biofuel. For what concerns management costs, the significant increase in productivity achieved exploiting a tractor equipped with forks for both collection, piling and transport (1 t/h) allows one to abate costs to about 60 €/t [7].

5.2.3 Olive Oil Chains Evaluation

The olive oil production chain can be made up considering different field, transport and plant scenarios for each phase of the chain, selected among those proposed in Sect. 5.2.1. In order to apply MCA to the whole production chain, as described in Chap. 2, it is essential to associate a global score with each chain arrangement, so that all arrangements can be compared to identify which ones have a higher level of sustainability, according to the adopted evaluation criteria. As a consequence, it is essential to define suitable rules to combine scores associated with each scenario in order to obtain the required global one.

If qualitative scores (*A*, *B* or *C*) are used, score combination is usually achieved by means of a decision ranking matrix [12]. The matrix used in the present application is reported in Table 5.5. It is a symmetrical matrix used to combine values two by two, obtaining one final global score for the whole chain. In some cases, it is possible to obtain different final scores by changing the order of couple evaluation, since this is a non-commutative operation. If this happens, the lowest possible value for the global score is chosen for conservative reasons.

Due to the large variability of possible evaluation criteria, only three qualitative scores are adopted in the present application. This choice allows one to combine different weights in a relatively simple way, reducing risks of ambiguous results in the determination of the final score associated with each chain arrangement, as discussed before. However, one of the main drawbacks of this simplified approach is that most arrangements may have the same score, preventing one from identifying the most significant ones and making the MCA approach ineffective. For this reason, additional numerical scores are associated with each criterion level, as described in Sect. 5.2.2. The final global score is determined both qualitatively, using the decision matrix of Table 5.5, and quantitatively, by averaging scores associated to each criterion level on the number of environmental and economic criteria separately, and then making a final average between the two. Qualitative and quantitative results are eventually compared.

Combining all scenarios identified for each phase of the olive oil chain, 14 different configurations are obtained (Table 5.6). A number of additional configurations have been discarded, since they do not represent realistic cases in applications. For example, all configurations in which the *F*1 scenario (marginal olive grove) is combined to a medium–sized olive mill with or without stone separator (*P*2 and *P*3 scenarios) are not taken into account. On the contrary,

Table 5.6 Olive oil chain evaluation throughout MCA

Chain	Scenarios			Environmental score						Economic score				Global score
				*CA*1	*CA*2	*CA*3	*CA*4	*CA*5	Total	*CE*1	*CE*2	*CE*3	Total	
1	*F*	*T*1	*P*1	*A*	*A*	*A*	*A*	*C*	**B**	*C*	*C*	*C*	**C**	**C**
				3	3	3	3	1	**2.60**	1	1	1	**1.00**	**1.80**
2	*F*1	*T*2	*P*1	*A*	*A*	*A*	*B*	*B*	**B**	*C*	*C*	*C*	**C**	**C**
				3	3	3	2	1	**2.40**	1	1	1	**1.00**	**1.70**
3	*F*2	*T*1	*P*1	*A*	*B*	*B*	*A*	*C*	**B**	*B*	*B*	*B*	**B**	**B**
				3	2	2	3	1	**2.20**	2	2	2	**2.00**	**2.10**
4	*F*2	*T*1	*P*2	*A*	*B*	*B*	*A*	*B*	**A**	*B*	*B*	*B*	**B**	**A**
				3	2	2	3	2	**2.40**	2	2	2	**2.00**	**2.20**
5	*F*2	*T*2	*P*1	*A*	*B*	*B*	*B*	*C*	**B**	*B*	*B*	*B*	**B**	**B**
				3	2	2	2	1	**2.00**	2	2	2	**2.00**	**2.00**
6	*F*2	*T*2	*P*2	*A*	*B*	*B*	*B*	*B*	**A**	*B*	*B*	*B*	**B**	**A**
				3	2	2	2	2	**2.20**	2	2	2	**2.00**	**2.10**
7	*F*3	*T*2	*P*2	*B*	*C*	*C*	*B*	*B*	**C**	*A*	*A*	*B*	**A**	**B**
				2	1	1	2	2	**1.60**	3	3	2	**2.67**	**2.13**
8	F3	*T*2	*P*3	*B*	*C*	*C*	*B*	*A*	**B**	*A*	*A*	*B*	**A**	**A**
				2	1	1	2	3	**1.80**	3	3	2	**2.67**	**2.23**
9	*F*3	*T*3	*P*2	*B*	*C*	*C*	*C*	*B*	**C**	*A*	*A*	*B*	**A**	**B**
				2	1	1	1	2	**1.40**	3	3	2	**2.67**	**2.03**
10	*F*3	*T*3	*P*3	*B*	*C*	*C*	*C*	*A*	**B**	*A*	*A*	*B*	**A**	**A**
				2	1	1	1	3	**1.60**	3	3	2	**2.67**	**2.13**
11	*F*4	*T*2	*P*2	*C*	*C*	*C*	*B*	*B*	**C**	*A*	*A*	*A*	**A**	**B**
				1	1	1	2	2	**1.40**	3	3	3	**3.00**	**2.20**
12	*F*4	*T*2	*P*3	*C*	*C*	*C*	*B*	*A*	**B**	*A*	*A*	*A*	**A**	**A**
				1	1	1	2	3	**1.60**	3	3	3	**3.00**	**2.30**
13	*F*4	*T*3	*P*2	*C*	*C*	*C*	*C*	*B*	**C**	*A*	*A*	*A*	**A**	**B**
				1	1	1	1	2	**1.20**	3	3	3	**3.00**	**2.10**
14	*F*4	*T*3	*P*3	*C*	*C*	*C*	*C*	*A*	**B**	*A*	*A*	*A*	**A**	**A**
				1	1	1	1	3	**1.40**	3	3	3	**3.00**	**2.20**

intensive and superintensive groves are only coupled with medium-sized mills collecting olives from a wider area than the single farm, possibly providing by–product reuse facilities.

For each configuration reported in Table 5.6, the total scores obtained by applying either environmental (from *CA*1 to *CA*5) or economic (from *CE*1 to *CE*3) criteria described in Table 5.4 are provided, both as a qualitative (*A*, *B* or *C*) and as a quantitative numerical result. A global score is eventually determined by combining the two partial scores by exploiting the decision matrix (Table 5.5) or averaging numerical ones.

The obtained global score is used for comparing configurations all together, and for identifying the most favourable ones, which are selected for the LCA analysis. As discussed in Chap. 3, there is no reason for giving more importance to either environmental or economic scores, since their corresponding criteria are completely independent of each other, and they are not comparable from a technical point of view. The introduction of an additional score to distinguish the contribution of these two factors can be justified only on a political basis, if decision makers decide to place environmental aspects before economic ones, or vice versa.

The results of the MCA analysis identify five configurations as more interesting for olive oil chain sustainability: n.4, 8, 11, 12 and 14. The highest score (*A* level, 2.30 points) is obtained by configuration n. 12. This is characterized by an excellent result in terms of economic criteria, due to a highly mechanized field management and a high olive yield, and by an average environmental score, mainly due to both prunings and pomace stone reuse. Configuration n. 8 (second in place: *A* level, 2.23 points) differs from the first one only for grove characteristics (intensive grove, *F*3 scenario), and for the use of a waterfall irrigation system without pumping plant. The remaining three configurations (n. 4, 11 and 14) obtain the same numerical score (2.20 points), even if n. 11 has a slightly lower qualitative score (*B* level) than the other two. However, while n. 11 and n. 14 are quite similar in terms of both environmental and economic features, configuration n.4 only, among the 5, has a total environmental score higher than the economic one. Its economic drawbacks, due to the low level of mechanization and low olive yields, are balanced by a lower environmental impact due to traditional grove management (absence of irrigation plants, organic fertilization) and simpler logistics, with an olive mill inside the farm which does not require transport and exploits bio-fuel for the heat boiler.

5.3 LCA Methodology Applied to the Olive Oil Chain

The LCA methodology, whose details are described and discussed in Chap. 2, is applied to the five best configurations identified by means of the MCA analysis, i.e. chains n. 4, 8, 11, 12 and 14 shown in Table 5.6. As for the other applications, the main target of LCA is to determine which one of these five chains have a lower impact on the environment, in terms of both $CO_{2\ eq}$ emissions and CER.

The application of LCA is carried out using the software GEMIS 4.5 [11]. This software exploits a large database collecting information about European bioenergy chains and biofuels. In order to use GEMIS, it is essential to set up an inventory phase. This operation consists in the collection of a number of data concerning all processes involved in the selected chains, which must be provided to the GEMIS software as inputs for performing LCA. Inventory data refers to process inputs in terms of raw materials required for field operations (water, fertilizers, pesticides), fuel and energy consumptions (oil, electricity, biomass) and wastes. A normalization of all data is required with respect to the unit product output of each process (i.e. the functional unit) in order to have results of LCA normalized as well.

Collection of data for the inventory phase is often a hard task to accomplish, due to the large variability in process inputs inside the same configuration, and the difficulty of finding consistent and complete data for all processes. At the same time, this operation represents a crucial point in the application of LCA methodology, since lack or inconsistency of data may turn out into incorrect evaluation of both $CO_{2\ eq}$ and CER outputs. For these reasons, particular care should be paid in collecting information for each chain configuration, cross-referencing data from different sources, if possible.

Data concerning the olive oil chain can be divided into four main groups

1. Olive grove data;
2. Prunings reuse data;
3. Transport data;
4. Olive mill data.

For what concerns the second group, prunings reuse, data are provided and discussed in detail in Chap. 3. The other data are presented here.

5.3.1 Olive Grove and Transport Data

Grove data required for performing LCA are:

- Olive yield;
- Water consumption;
- Type (organic/mineral) and amount of employed fertilizers, distinct for active principle;
- Pesticide consumption;
- Fuel consumption.

Three different field scenarios are considered in the five chain configurations selected using MCA: *F*2, *F*3 and *F*4. Data concerning each scenario are reported and discussed here.

For what concerns olive yield, input data are computed for each scenario considering tree density and tree average production, reported in Sect. 5.2.2.

Data are normalized with respect to the annual olive production of 1 ha of olive grove:

*F*2 scenario: considering a tree density of 250 trees/ha and a tree production of 20 $\text{kg}_{\text{olives}}$/ (tree year), an overall production of 5,000 $\text{kg}_{\text{olives}}$/(ha year) is estimated;
*F*3 scenario: a tree density of 500 trees/ha and an average tree production of 10 $\text{kg}_{\text{olives}}$/ (tree year) lead to an overall production of 5,000 $\text{kg}_{\text{olives}}$/(ha year), equivalent to *F*2 scenario;
*F*4 scenario: in this case, the higher tree density of about 800 trees/ha compensates the lower average tree production of 8 $\text{kg}_{\text{olives}}$/tree year, resulting in a higher overall production of 6,400 $\text{kg}_{\text{olives}}$/(ha year).

The results of this evaluation are consistent with the data provided by EFNCP/ARPA [9], as reported in Sect. 5.2.2.

Water consumption for irrigation is not easy to quantify, since it is strongly variable, depending on many factors, such as the geographical area where the grove is located, its climatic and topographic conditions, average rainfall, evapotranspiration and temperatures, soil types, water availability along the year, and so on. For the present analysis, two field scenarios exploit grove irrigation (*F*3 and *F*4). A rough estimate of water consumption for the two is obtained considering data provided by EFNCP/ARPA [9], which gives a water amount range between 1,500 m^3/(ha year) and 5,000 m^3/(ha year), relying on several case studies carried out in the Mediterranean area. Considering the minimum and maximum amounts for *F*3 and *F*4 scenarios, respectively, and normalizing data with the annual olive yield per hectare, an estimate of 300 kg_{water}/ $\text{kg}_{\text{olives}}$ for *F*3 scenario, and 781 kg_{water}/ $\text{kg}_{\text{olives}}$ for *F*4 scenario is obtained.

For what concerns fertilization, organic fertilizers are employed in *F*2 scenario and mineral fertilizers in both *F*3 and *F*4 scenarios. Data concerning both fertilizers quantities and active principles are obtained by Recchia et al. [13], who collected experimental data in a number of Tuscany farms. Similar quantities and principles are assumed for all scenarios. Normalized fertilizer amounts per kg of produced olives are reported in Table 5.7.

Similar considerations as for fertilizers can be made for the amount of pesticides. In Tuscany, many farms either do not perform plant health control, or exploit basic sanitary treatments using copper sulphate. Here, an average quantity of 6 kg of copper sulphate per hectare is assumed for all scenarios, relying on data available from some Tuscany farms. Normalized amounts per kg of produced olives are provided in Table 5.7.

The evaluation of fuel consumption in field management is more complex, since it must take into account several operations carried out with a variety of devices. In the present application, fuel consumptions related to prunings operations and management, fertilization and disinfestation, and olive harvest are considered for the three scenarios *F*2, *F*3 and *F*4. Inventory data are presented in Tables 5.8, 5.9, 5.10.

The global consumption for each field operation in terms of diesel fuel, typically used in agricultural machines, is computed according to Eq. 5.1:

Table 5.7 Summary of grove inventory data for the 5 most sustainable olive oil chains

Chain			4	8	11	12	14
Grove scenarios	Units	Notes	F2	F3	F4	F4	F4
Olive yield	kg/(ha year)		5,000	5,000	6,400	6,400	6,400
Water consumption	kg/$\text{kg}_{\text{olives}}$		0.00	300	781	781	781
Fertilizer type			Organic	Mineral	Mineral	Mineral	Mineral
Fertilizer active principle	kg/$\text{kg}_{\text{olives}}$	*P*	0.00275	0.00275	0.00275	0.00275	0.00275
	kg/$\text{kg}_{\text{olives}}$	*Ca*	0.006143	0.006143	0.006143	0.006143	0.006143
	kg/$\text{kg}_{\text{olives}}$	*N*	0.005143	0.005143	0.005143	0.005143	0.005143
	kg/$\text{kg}_{\text{olives}}$	*K*	0.009107	0.009107	0.009107	0.009107	0.009107
Pesticides	kg/$\text{kg}_{\text{olives}}$		0.0012	0.0012	0.000938	0.000938	0.000938
Fuel consumption	kWh/$\text{kg}_{\text{olives}}$		0.14	0.50	0.55	0.55	0.55

Table 5.8 Fuel consumption data for *F*2 field scenario

Field operation	Notes	Nominal device power (kW)	Average utilization (%)	Usage time (h/ha)	Energy consumption (kWh/ha)
Prunings	Operation management	4.50	60	10.00	64.04
		50.00	60	3.00	213.48
Fertilization		50.00	60	2.50	177.90
Disinfestation		50.00	60	2.50	177.90
Harvest	Vibrating poles	1.25	60	50.00	88.95
Total					722.27

Table 5.9 Fuel consumption data for *F*3 field scenario

Field operation	Notes	Nominal device power (kW)	Average utilization (%)	Usage time (h/ha)	Energy consumption (kWh/ha)
Prunings	Operation management	4.50	60	10.00	64.04
		50.00	60	3.00	213.48
Fertilization		50.00	60	2.50	177.90
Disinfestation		50.00	60	2.50	177.90
Harvest	Shaker with umbrella	60.00	60	21.88	1,867.95
Total					2,501.27

$$\begin{aligned}\text{Energy consumption} &= \text{Nominal device power(NDP)}\\ &\times \text{Average utilization(AU)} \times \text{Specific fuel consumption(SFP)}\\ &\times \text{Lower heating value(LHV)} \times \text{Usage time(UT)}.\end{aligned} \tag{5.1}$$

Table 5.10 Fuel consumption data for *F*4 field scenario

Field operation	Notes	Nominal device power (kW)	Average utilization (%)	Usage time (h/ha)	Energy consumption (kWh/ha)
Prunings	Operation management	10.00	60	2.00	28.46
		30.00	60	3.00	128.09
Fertilization		50.00	60	2.50	177.90
Disinfestation		50.00	60	2.50	177.90
Harvest	Shaker with umbrella	60.00	60	35.00	2,988.72
Total					3,501.07

Reference values for SFP = 0.2 kg/kWh and LHV = 11.86 kWh/kg are available from the literature [5, 10], and are assumed constant for each device in each scenario, as well as an average device power utilization AU = 60%. The other data are provided by Cresti et al. [7], which exploit data referring to typical Tuscan farms.

Detailing each scenario, *F*2 values reported in Table 5.8 are obtained in the following way. For prunings operation, the use of pneumatic scissors is assumed (Fig. 5.10), with NDP = 4.5 kW, considering a usage time UT = 10 h/ha (2 h/ha for five workers), while prunings management is performed using a 50 kW farm tractor requiring 3 h/ha. Both fertilization and disinfestation use the same 50 kW tractor capable of treating 100 trees/h for a density of 250 trees/ha. Harvest is managed by means of vibrating poles, (NDP = 0.250 kW) for five workers, each employing about 10 h/ha (Fig. 5.11).

*F*3 values (Table 5.9) differ from *F*2 ones only for what concerns harvest management, which is fully mechanized and exploits a 60 kW olive shaker equipped with a gathering umbrella for collecting olives (Fig. 5.12). The value for UT = 21.88 h/ha is computed dividing the tree density 500 trees/ha by the machine working capacity (approximately 160 trees/day for a 7 h/day working time).

Considering *F*4 scenario, differences with respect to the other two concern both prunings operations and management, and harvest. Prunings operations are performed by means of a machine equipped with cutting bars with serrated plates (NDP = 10 kW) requiring a UT = 2 h/ha (Fig. 5.13). Prunings are treated for energetic reuse by exploiting an industrial shredder, capable of collecting, shredding and transporting prunings (NDP = 30 kW, UT = 3 h/ha) (Fig. 5.14). Olive harvest is achieved by means of an olive shaker with a gathering umbrella, as in *F*3 scenario, but for the required average usage time (UT = 35.00 h/ha) due to the higher value of tree density (800 trees/ha).

For transport scenarios *T*1, *T*2 and *T*3, LCA inventory data only concerns employed means of transport and distances from the grove to the olive mill. These data are reported in Tables 5.2 and 5.11. While *T*1 does not require any transport, exploiting farm tractors (Fig. 5.3), *T*2 considers a 5 km distance covered by means of pick-up vans, and *T*3 a 30 km distance with transport operated by lorries.

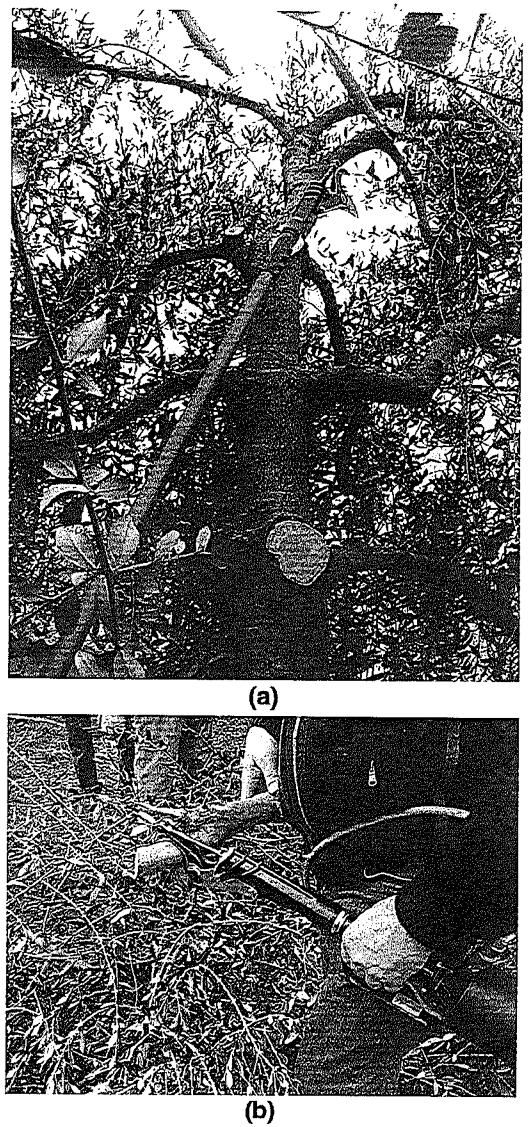


Fig. 5.10 Pneumatic scissors for prunings operations (from Cresti et al. [7]). **a** Fixed scissors with telescopic arm, **b** pneumatic scissors

5.3.2 Olive Oil Mill Data

Olive mill data required by LCA methodology are:

- Oil extraction efficiency;
- Oil production;

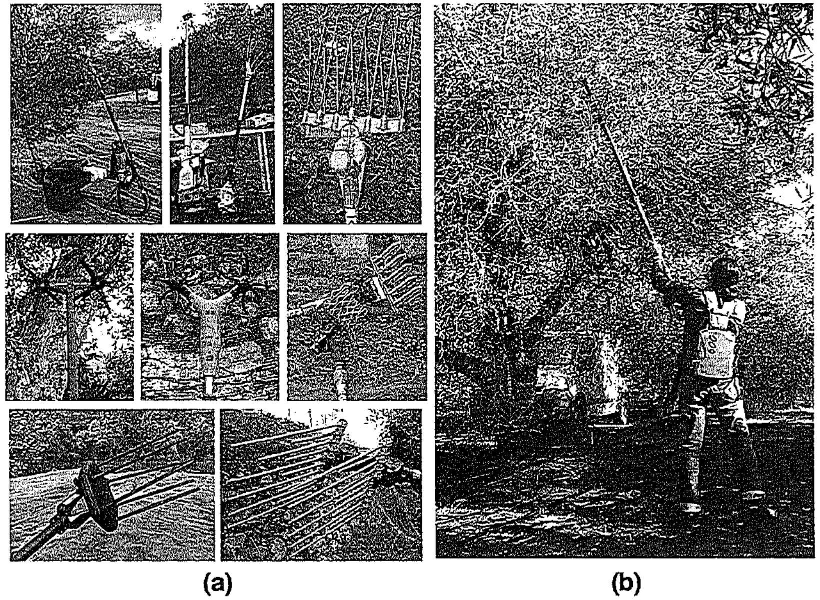


Fig. 5.11 Vibrating poles for harvesting operations (from Cresti et al. [7]). **a** Different commercial typologies, **b** vibrating pole usage

- Operative and life time of olive mill device equipment;
- Electricity consumption and type of power plant;
- Heat consumption and type of heat plant;
- Water consumption;
- Waste typology and quantity.

Two extraction plant scenarios are considered in the five chain configurations selected using MCA, *P*2 and *P*3, which essentially differ about pomace stone reuse as biofuel. Data concerning each scenario are reported and discussed here (Table 5.12).

Olive oil extraction efficiency typically varies in a range between 10 and 20% of olive mass flow processed in the mill. Variations are due to several factors (type of cultivar, ripening level, extraction plant management, ...), which are difficult to predict. In this application, an average value of 15% is assumed for both scenarios, which represents a typical value for Tuscan production.

Both olive mills are supposed to be operative for about 3 months a year, from October to December, during olive harvest. In this short period, working times often extend over many hours a day, in order to face peak-time demand from farms. In recent years, this has become a fundamental requirement for extraction plants, since milling olives within 24 h from harvest has been proved to be essential for obtaining high-quality extra virgin olive oil. As a consequence, a daily working time of 16 h a day is considered in the present application, for 30 days a month, resulting in an estimated global amount of working hours equivalent to 1,440 h/year for both scenarios. Assuming a mill working capacity of 350 $\mathrm{kg_{olive}}$/h and a 15% extraction efficiency, the overall oil production is 75,600 $\mathrm{kg_{oil}}$/year.

Fig. 5.12 Olive shaker equipped with a gathering umbrella (from Cresti et al. [7])

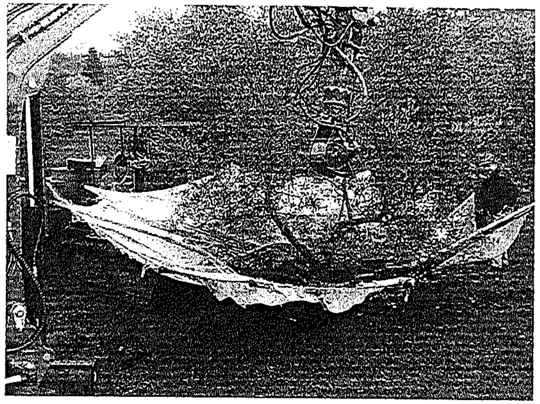


Fig. 5.13 Farm tractor equipped with cutting bars with serrated plates (from Cresti et al. [7])

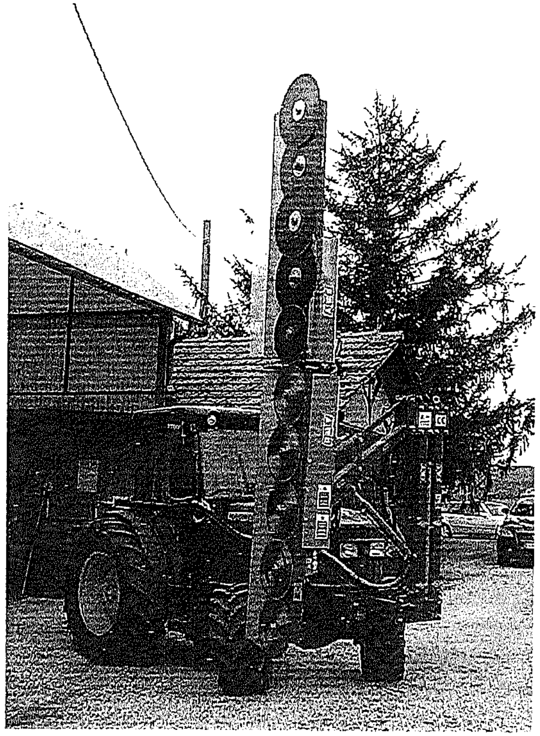


Fig. 5.14 Devices for collecting, shredding and transporting prunings (from Cresti et al. [7])

The lifetime of mill equipment varies from device to device. Considering only mechanical devices (olive crusher, kneading machine, centrifugal decanter, pomace stone separator and auxiliary equipments), a lifetime of 4 years is considered a reasonable estimate, according to manufacturers' handbooks and instructions.

For what concerns electricity consumptions, both *P*2 and *P*3 scenarios are supposed to exploit electric grid power. Similar configurations for both plants are considered, with an olive crusher, a vertical kneading machine and a two-phase centrifugal decanter, the only difference being the use of a centrifugal pomace stone separator in *P*3 scenario. Since the working capacity is the same (300 kg_{olives}/h), all nominal powers are assumed to be the same for devices present in both plants. Detailed data for two extraction plants similar to *P*2 and *P*3 are provided by Cini et al. [6] and shown in Table 5.13 for completeness. For each operation and sub-operation of the extraction process the nominal device power and its usage percentage and time are reported. Times have been directly measured during extraction operations at the olive oil mill, while usage percentages have been either measured or afterward deduced from global electricity consumptions. Energy consumptions

Table 5.11 Summary of transport plant inventory data for the 5 most sustainable olive oil chains

Chain			4	8	11	12	14
Transport scenarios	Units	Notes	T1	T2	T2	T2	T3
Means of transport			–	Pick-up Van	Pick-up Van	Pick-up Van	Lorry
Distance	km		–	5	5	5	30

are reported both as absolute and specific values per each kilogram of extracted olive oil. As a result, this study estimates an overall average consumption of 0.195 kWh/kg_{oil} and 0.314 kWh/kg_{oil} for *P*2 and *P*3 scenarios, respectively. Therefore, the increase in energy consumptions due to the use of a stone separator (*P*3 scenario) is about 61% of the whole consumption without it (*P*2 scenario).

Heat consumptions required for mill management are estimated considering an average specific consumption of 50 kWh/ (m^2 year) for both scenarios. This value can be compared to typical values for a residential building in Italy, which are about 200–250 kWh/ (m^2 year). The much lower value is essentially due to the fact that heating of olive mill premises is limited to what is strictly necessary. Assuming a mill surface of 200 m^2, the resulting heat consumption is 0.132 kWh/kg_{oil}. For what concerns the type of heat plant, *P*2 scenario is equipped with a biomass heat boiler using prunings. This is also the case of the *P*3 scenario, where, in addition, stone extracted from pomace is sold as a biofuel, as discussed in Sect. 5.2.1.

Mill water requirements are strongly variable, depending on both olive type and quality, and mill configuration. Focusing the attention on the extraction process, olive washing and oil separation in the centrifugal decanter are the two most water-consuming operations [1]. In the present application, a two-phase centrifugal decanter is considered for oil extraction, which greatly reduces water consumptions with respect to three-phase decanters. Water added at a two-phase decanter input is typically 10% of the pomace mass flow (10 kg of water per 100 kg of processed olives). In addition, 20 kg of water is required for washing and 17 kg for rinsing 100 kg of olives. No water is added in the pomace stone separator (*P*3 scenario), since water content in the pomace exiting the two-phase decanter is sufficient to perform stone separation. As a result, an overall average specific water consumption of 3.13 kg/kg_{oil} is obtained with 15% extraction efficiency.

Wastes at the end of the extraction process basically consist of vegetation water and pomace. Considering a two-phase decanter processing 100 kg of olives with the addition of 10 kg of water, as discussed before, about 4 kg of vegetation water (0.26 kg/kg_{oil}) and 91 kg of pomace (6.07 kg/kg_{oil}) are typically obtained at the decanter outlet. So, the global waste quantity in *P*2 scenario sums up to 6.33 kg/kg_{oil}. In *P*3 scenario, pomace is destoned by means of a centrifugal separator, which is reused as a biofuel and is not treated as waste. Considering an average solid content of about 40% on olive mass, the typical efficiency of the stone extraction process is

Table 5.12 Summary of extraction plant inventory data for the 5 most sustainable olive oil chains

Chain			4	8	11	12	14
Plant scenarios	*Units*	*Notes*	*P2*	*P3*	*P2*	*P3*	*P3*
Extraction efficiency	%		15	15	15	15	15
Operative time	h/year		1,440	1,440	1,440	1,440	1,440
Life time	year		4	4	4	4	4
Olive oil production	kg/year		75,600	75,600	75,600	75,600	75,600
Electricity power plant			Grid	Grid	Grid	Grid	Grid
Electricity consumption	kWh/ kg_{oil}		0.195	0.314	0.195	0.314	0.314
Heat power plant		Biomass heat boiler	Prunings	Prunings (pomace stone sold as biofuel)	Prunings	Prunings (pomace stone sold as biofuel)	Prunings (pomace stone sold as biofuel)
Heat consumption	kWh/ kg_{oil}		0.132	0.132	0.132	0.132	0.132
Water consumption	kg/kg_{oil}	2-phase decanter	3.13	3.13	3.13	3.13	3.13
Waste type			Vegetation water and pomace	Vegetation water and destoned pomace	Vegetation water and pomace	Vegetation water and destoned pomace	Vegetation water and destoned pomace
Waste quantity	kg/kg_{oil}		6.33	5.42	6.33	5.42	5.42

about 15% on olive mass as well [6]. Consequently, the total amount of wastes decreases to 5.42 kg/kg_{oil}.

5.4 LCA Results

The results of LCA methodology applied to the 5 chains selected by means of MCA are provided and discussed here. In Table 5.13, numerical outputs from the GEMIS software are reported in terms of both $CO_{2\ eq}$ emissions and CER for all chains. The results are also illustrated in Figs. 5.15 and 5.16.

For what concerns $CO_{2\ eq}$ emissions, contributions due to different operations associated with each phase of the production chain (field operations, transport and extraction process) are provided. As a result of LCA analysis, most $CO_{2\ eq}$ emissions are due to field operations. A much lower impact is due to both extraction process and transport, the latter being almost negligible.The total emission amounts are computed by summing up all contributions, which are considered as "debits" in terms of environmental impact. Moreover, for three of the selected chains (n. 8, 12 and 14) a number of "credits" are introduced, related to the reuse of pomace stone as a biofuel in the scenarios composing each chain. Actually, by-product reuse lowers the global amount of $CO_{2\ eq}$ emissions, since it allows one to partially replace the use of non-renewable resources for energy production (oil, natural gas) with renewable ones. On the other hand, prunings are employed in the extraction plant for thermal energy production, and their reuse does not provide any credit, since it is exploited inside the production chain. The total emission amounts accounting for these credits are reported in Table 5.14 and Fig. 5.15.

Comparing results for the five chains, Chain 4 turns out to be the most favourable in terms of both $CO_{2\ eq}$ emissions and CER. As discussed in Sect. 5.2.3 while commenting on MCA results, this chain is the only one having a total environmental score higher than the economic one, due to a low level of mechanization in the grove management. In this chain, the *F*2 scenario does not collect olive tree prunings, which can be either burned or shredded and landfilled. In the first case, emissions associated with burning operations are not considered. In the second case, no increase in soil fertility is taken into account, since the highest contribution is due to organic matter, while no significant amount of nutrients is delivered in the short period to the soil. However, since *P*2 scenario, included in chain 4 as well, makes use of prunings as a biofuel, an external supplying source of prunings is assumed, located at a transport distance lower than 40 km. Related impacts, computed considering the agro-energetic chain n. 18 described in Chap. 3, amount to 38.267 kg $CO_{2\ eq}$ /kWh ($CO_{2\ eq}$ emissions) and 0.077 kWh/kWh(CER).

In Chain 8, which is second on the list, some benefits in $CO_{2\ eq}$ emissions are accounted for considering the reuse of prunings in the extraction phase for thermal energy production (*F*3 scenario). Their evaluation is performed referring again to the agro-energetic chain n. 18 described in Chap. 3.

Table 5.13 Working process powers and energy consumptions for *P*2 and *P*3 scenarios (data from Cini et al. [6])

Operation	Sub-operation	Nominal device power (kW)	Average utilization (%)	Usage time (h)	Energy consumption	
					Absolute (kWh)	Specific (kWh/kg$_{oil}$)
Defoliation-Washing		1.77	100	0.36	0.63	0.0140
Crushing	Cutting	5.50	51	0.36	1.00	0.0224
	Auxiliary equipment	1.86	100	0.36	0.66	0.0147
Kneading		1.10	100	1.00	0.63	0.0245
Extraction	Centrifugation	5.00	56	0.54	4.49	0.1003
	Auxiliary equipment	1.50	100	0.54	0.80	0.0179
Filtration		0.75	100	0.07	0.05	0.0011
P2 Total		**27.5**	**66.3**	**2.31**	**8.74**	**0.195**
Stone separation		15.00	66.3	0.54	5.32	0.1186
P3 Total		**42.5**	**66.3**	**2.85**	**14.06**	**0.314**

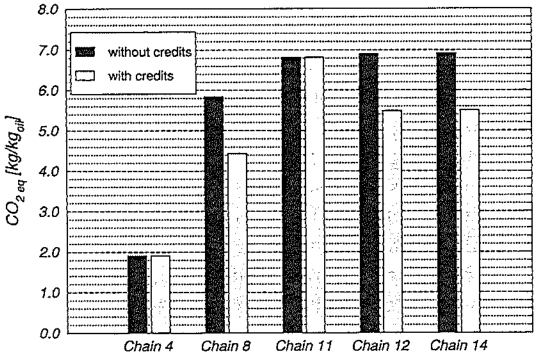


Fig. 5.15 $CO_{2\ eq}$ emissions for the five most suitable olive oil chains

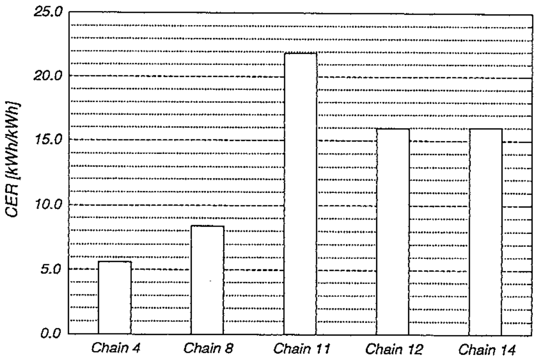


Fig. 5.16 CER emissions for the five most suitable olive oil chains

Table 5.14 $CO_{2\ eq}$ and CER emission results from LCA applied to the five most suitable olive oil chains

	Chain 4	Chain 8	Chain 11	Chain 12	Chain 14
$CO_{2\ eq}$ (kg/kg$_{oil}$)					
Field operations	1.771	5.630	6.686	6.686	6.686
Transport	0.000	0.003	0.003	0.003	0.019
Extraction process	0.134	0.212	0.134	0.212	0.212
Total without credits	1.906	5.846	6.823	6.901	6.917
Total with credits	1.906	4.441	6.823	5.496	5.512
CER (kWh/kg$_{oil}$)	5.589	8.396	21.878	15.957	16.014

Chains 11, 12 and 14 essentially differ for the extraction plant scenario (*P*2 for Chain 11, *P*3 for Chains 12 and 14). For what concerns wastes produced during olive oil extraction, they are not contemplated in the present analysis, since spreading in field is provided for in both scenarios, and no differences can be highlighted between them. In fact, the same quantity of nutrients are delivered to soil, since pomace stone contributions are negligible. The chain results in terms of $CO_{2\ eq}$ emissions are quite similar for all the three, if credits are not taken into account. However, significant credits are obtained for Chains 12 and 14 from the reuse of pomace stone (*P*3 scenario), which is sold as a biofuel, as previously discussed in this section and in Sect. 5.2.1. Credits coming from the use of pomace stone instead of natural gas are computed as follows [11]. The amount of CH_4 replaced by pomace stone is given by Eq. 5.2:

$$m_{CH_4}\,(kg) = m_{stone}\,(kg) \times \left(\frac{LHV_{stone}}{LHV_{CH_4}}\right) \times \left(\frac{0.85}{0.95}\right), \tag{5.2}$$

where:

$$LHV_{stone} = 4.5\ kWh/kg,$$

and

$$LHV_{CH_4} = 13.5\ kWh/kg.$$

Credits are eventually computed according to GEMIS process *"gas-boiler-CZ-small (2000)"* [11] for both $CO_{2\ eq}$ (Eq. 5.3):

$$Credits_{CH_4}(CO_{2eq}) = -0.30701\ kg\,CO_{2eq}/kWh_{CH_4}; \tag{5.3}$$

and CER (Eq. 5.4):

$$\mathrm{Credits}_{CH_4}(\mathrm{CER}) = -0.077\ \mathrm{kWh/kWh}_{CH_4}. \qquad (5.4)$$

The total amount of credits is –1.405 kg $CO_{2\ eq}/kg_{oil}$, which is subtracted from the total emission results of chains 8, 12 and 14 in Table 5.14.

References

1. ARPAL (2006) Analisi ambientale di comparto produttivo. L'olio d'oliva. Technical report, Agenzia Regionale per la Protezione dell'Ambiente Ligure (ARPAL)
2. Avraamides M, Fatta D (2008) Resource consumption and emissions from olive oil production: a life cycle inventory case study in cyprus. J Cleaner Prod 16:809–821
3. Chiaramonti D, Recchia L (2009) Life cycle analysis of biofuels: can it be the right tool for project assessment? In: 17th European biomass conference and exhibition from research to industry and markets, Hamburg, 29 June–2 July 2009
4. Chiaramonti D, Recchia L (2010) Is life cycle assessment (LCA) a suitable method for quantitative CO_2 saving estimations? The impact of field input on the LCA results for a pure vegetable oil chain. Biomass Bioenergy 34:787–797
5. Cini E, Recchia L (2008) Energia da biomassa: un'opportunità per le aziende agricole
6. Cini E, Recchia L, Daou M, Boncinelli P (2008) Human health benefits and energy savings in olive oil mills. In: International conference on "Innovation technology to empower safety, health and welfare in agriculture and agro-food systems", Ragusa, Italy, September 15–17
7. Cresti G, Gucci R, Zorini LO, Polidori R, Vieri M, Sarri D, Rimediotti M (2009) Progetto MATEO. Modelli tecnici ed economici per la riduzione dei costi di produzione nelle realtà olivicole della Toscana. Technical report, ARSIA Toscana
8. Dessane D (2003) Energy efficiency and life cycle analysis of organic and conventional olive groves in the Messara Valley, Crete, Greece. Master's thesis, Wageningen University
9. EFNCP/ARPA (2000) The environmental impact of olive oil production in the EU: practical options for improving the environmental impact. Technical report, European Forum on Nature Conservation and Pastoralism and the Asociación para el Análisis y Reforma de la Política Agro-rural
10. ENAMA (2005) Prontuario dei consumi di carburante per l'impiego agevolato in agricoltura. Technical report, Ente Nazionale per la Meccanizzazione Agricola
11. GEMIS (2010) Global emission model for integrated systems (GEMIS). Oko-Institut e.V. http://www.oeko.de/service/gemis/
12. Recchia L, Cini E, Corsi S (2010) Multicriteria analysis to evaluate the energetic reuse of riparian vegetation. Appl Energy 87:310–319
13. Recchia L, Gaertner S, Corsi S (2010) LCA applied to agro-industrial products: the case of the vegetable oils in Tuscany. In: LCAfood 2010—VII International conference on life cycle assessment in the agri-food sector, Bari, Italy, September 22–24

Chapter 6
Oil Palm Farming Chain

6.1 Introduction

This chapter focuses on an Multicriteria analysis (MCA) based decision scheme and the related life cycle assessment (LCA), aimed to compare some possible scenarios that planners could have to face when evaluating the convenience of different options when establishing an oil palm plantation.

Higher yields and lower production costs, if compared to other edible oil sources, have focused great interest in oil palm cultivation since the 1970s [10], mainly in Southeast Asia Countries, but also in its areas of origin of Western and Central Africa and in more recently exploited Latin America and Caribbean. In the last years the increase in demand for vegetable oil for biodiesel and the support given by Governments of the main producing Countries, donors, funding institutions and the UN to the large-scale agro-industrial model, have given even more impulse to its expansion making it the fastest growing monocrop plantation in the tropics, with almost 15 Mha standing in 2009 [2].

Due to the uncontrolled booming of commercial plantations that has taken place at the end of the last century and to the consequent negative environmental impact, in the last decades large projects for oil palm have often been criticized and opposed [9]. The need for a more careful and responsible approach, that takes into account not only economical results but also environmental and social aspects of planting in large scale, is nowadays universally recognized and new investments cannot ignore these aspects. This positive response to the so-called sustainable approach and its rules has reduced the land soundly suited for new plantations and has called for more careful analysis of cultivation inputs and techniques, making it necessary, in some cases, to take into account even the need for irrigation.

Large-scale plantations are now also facing a controversial moment where traditional employment of manual labour for most field operations is confronted with increasing labour costs, local unavailability of sufficient labour force and

L. Recchia et al., *Multicriteria Analysis and LCA Techniques*,
Green Energy and Technology, DOI: 10.1007/978-0-85729-704-4_6,