Energetic Use of Biomass and Biofuels

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Chapter 3
Energetic Use of Biomass and Biofuels

3.1 Introduction

Mediterranean countries produce 95% of the total world olive oil production estimated to be 2.4 million tonnes per year. Olive production is a significant land use in the southern Member States of the EU with important environmental, social and economical implications. The main areas of olive oil production are located in Spain (2.4 million ha), followed by Italy (1.4 million ha), Greece (1 million ha) and Portugal (0.5 million ha). France is a much smaller producer, with 40,000 ha.

In fact, data produced in 2000 by the EC's "Oliarea" survey [5] indicate a total olive area in Italy of 1.4 million ha, which represents a 400,000 ha increase compared with the area existing at the beginning of the 1990s and this is the tendency observed during the last decade. Moreover, based on data of the 5th Agricultural Census developed by ISTAT in 2000 and updated in 2005, the Tuscany region is characterised by a land use which promotes olive-groves occupying 18% of the total arable land.

However, in Italy there are several typologies of olive-groves because of different geographical area and site characteristics. Olive-groves may stronger differ by trees density which may vary from 50 to 400 plants/ha, from older plantations to the newer ones. Therefore, these different typologies of olive-groves require very different management practices: the lower tree density, the lower frequency of pruning operations of the trees crown.

The trees density also determines specific water requirements in order to assure elevated yields and to limit the competitions between the plants. For this reason the water availability is often considered as the most important limiting factor which, in fact, determines the olive-groves characteristics. Literature [5] declares that "under rain-fed cultivation, the lower the rainfall, the lower the tree density, by necessity". The water supply through an efficient irrigation system may assure sufficient yields even if the rainfalls are reduced, but the increases of the

L. Recchia et al., *Multicriteria Analysis and LCA Techniques*,
Green Energy and Technology, DOI: 10.1007/978-0-85729-704-4_3,

Fig. 3.1 Manual pruning in a typical olive-grove (Azienda Belvedere, Castiglion della Pescaia, Grosseto)

production costs and of the environmental pressures may be carefully taken into account.

Pruning is an important aspect of olive-grove management. In fact, trees may be pruned every year or every two or more years, depending on local tradition, individual farmer decisions, etc. In Tuscany, in some marginal situations or in particular areas where some constraints for preserving the landscape are fixed, trees are not pruned for many years and develop high dense canopies: this practice could cause problems in terms of workers' safety during olive harvesting and could also significantly increase the costs (see lower yield and higher harvesting time per plant).

Pruning operations are usually effectuated manually with chainsaws (see Fig. 3.1) and require a large labour input (i.e. one-fifth to one-third of the total labour on traditional farms). Recently, new varieties that can be mechanically pruned and consequentially are able to reduce significantly the labour needed, have started to be cultivated. This is the case of the so-called "bush" varieties planted in dense rows.

The Literature highlights that pruning must be carefully taken into account in order to assure the health of the trees: it is known that regular pruning and the adoption of specific codes of practice are able to decrease drastically pest or fungi risks. In addition, a crown with limited size allows to reduce the amount of pesticides needed with minor environmental risks.

Nevertheless, pruning residues management is a complicated and expensive agricultural operation. In Italy, usually, farms manage olive tree prunings in three different ways: harvesting and burning in the headlands; shredding and landfilling; harvesting, conditioning and storing for energetic use.

Each of these techniques is characterised by both advantages and disadvantages [8], as briefly shown in Table 3.1.

In addition, it is possible to affirm that choosing how to manage olive tree pruning depends on several factors and the most important one is the economical sustainability of the whole agro-energetic chain: it must be assured that the biofuel production cost is convenient and comparable with those of fossil fuels. Considering that one of the most critical aspects of agro-energetic chains is the low

Table 3.1 Pros and cons for different management systems of pruning residues [22]

Management of olive tree pruning	Advantages	Disadvantages
Harvesting and burning in headland This operation is done in olive-groves where pruning is manually carried out	Branches with larger diameter (>4–5 cm) can be selected and used as biofuels in wood stoves or fireplaces	High quantity of labour is required in order to move residues from field to the headland Several municipal laws forbid to burn pruning and other residues in field because of fire risk and air pollution
Shredding in field and landfilling The pruning residues are windrowed, shredded and then landfilled or left in field	No transports are necessary No areas must be dedicated for temporal storage of pruning residues Pruning residues are able to increase the organic matter in the soil because in a few months they are completely mineralized	Residues can be a diffusion means of several pests from tree to tree High quantity of labour is required
Harvesting and energetic use The pruning residues are windrowed, shredded and used as biofuel in an energy production plant	Environmental benefits in terms of CO_2eq savings Economical benefits in terms of reduction of the use of fossil fuels Partial independence from traditional fuels	Logistics is complex Storage areas must be provided

density of the biomass on the territory, which implies low operative capacities during the harvesting phase and significant transport distances, it is important to correctly evaluate the available quantity of pruning for specific areas of interest.

Taking into account all the existing varieties of management and also all the possible differences in site characteristics (with particular attention to land extension, plant yield, agronomical characteristics of the variety, soil fertility, etc.), pruning density may vary a lot.

The Literature reports several methodologies to estimate the biomass quantity, as the empirical equation developed by the ANPA [2] and reported in the following

$$\text{olive tree pruning on dry basis } (t_{db}/\text{ha/year}) = 0.566 \times \text{yield } (\text{t/ha/year}) + 1.496.$$

According to the formula, Ambiente Italia [1] indicates quantities of about 1.0–4.0 t_{db}/ha/year, whilst ITABIA [17] suggests values of 0.2 and 0.8 t_{db}/ha/year for wood and foliage of olives, respectively.

Moreover, tests carried out by the University of Florence during the previous years allowed to collect data for various areas of the Provinces of Firenze, Grosseto and Siena:

- Experimental harvesting conducted at the Montepaldi farm in the Province of Firenze, has detected an average density on wet basis of 5.0 t_{wb}/ha/year [18];

Table 3.2 Physical and chemical characteristics of olive tree pruning [9]

Parameters	Units	Standard values	Standard ranges
Moisture	%	47.0 (wood); 62.0 (foliage)	45.0–50.0 (wood); 60.0–65.0 (foliage)
LHV	MJ/kg_{db}	19.0	18.4–19.1
C content	$\%_{db}$	52.0	50.0–53.0
H content	$\%_{db}$	6.1	5.9–6.3
O content	$\%_{db}$	41.0	40.0–44.0
N content	$\%_{db}$	0.5	0.3–0.8
S content	$\%_{db}$	0.04	0.01–0.08
Cl content	$\%_{db}$	0.01	<0.01–0.02
Ca content	$\%_{db}$	4,000	3,000–5,000
Mg content	$\%_{db}$	250	100–400
Na content	$\%_{db}$	100	20–200
P content	$\%_{db}$	300	–
Si content	$\%_{db}$	150	7–250
Cd content	$\%_{db}$	0.1	–
Hg content	$\%_{db}$	0.02	–
Pb content	$\%_{db}$	5.0	–
K content	$\%_{db}$	1,500	1,000–4,000
Ash content	$\%_{db}$	1.7 (wood); 6.0 (foliage)	1.5–2.0 (wood); 5.0–7.0 (foliage)

- Close to Grosseto, multiple sampling has been carried out [7] measuring a density of 2.0–3.0 t_{wb}/ha/year;
- Tests executed at the farm Castello di Fonterutoli in the Province of Siena have highlighted values much lower than the previous one ranging between 0.8 and 1.6 t_{wb}/ha/year for 1- and 2-year pruning, respectively [8].

Therefore, in this work an indicative density on wet basis of 1 t_{wb}/ha/year for 1-year pruning has been fixed.

Finally, once the available quantity has been estimated and the use of pruning as biofuel has been chosen, it is useful to make some considerations about the energetic characteristics of these residues. Table 3.2 reports the physical and chemical characteristics of olive tree pruning. These values may vary if some harvesting conditions occur as briefly indicated in Table 3.3, decreasing the performances (efficiency, durability, etc.) of the energy plant.

In any case, for the present work a lower heating value (LHV) of 11.3 MJ/kg_{wb}, equal to 3.154 kWh/kg_{wb}, has been established.

3.2 Goals, Definitions and Decision Makers' Typology

The aims of the present work are:

- Defining all the scenarios identifying the possible harvesting yards, transport conditions and energetic plants;

Table 3.3 Possible causes of variation of some pruning characteristics [9]

Characteristic variation	Possible causes
Higher ash content	Earth contamination
	Higher content of bark
	Inorganic added compounds
	Chemical treatments
Lower/higher LHV	Presence of material with lower/higher LHV
Higher content of N	Higher content of bark
	Content of plastic materials mixed with
Higher content of S	Higher content of bark
	Inorganic added compounds
	Chemical treatments
Higher content of Cl	Higher content of bark
	Wood coming from coastal zones
	Contamination with salt (i.e. salt used on roads in winter time)
	Chemical treatments (i.e. compounds used to preserve the wood)
Higher content of Si	Earth contamination
	Higher content of bark
Higher content of Ni	Contamination through machine used for conditioning
	Mineral oil
Higher content of Pb	Environmental contamination (e.g. vehicle traffic)
	Content of plastic materials mixed with
	Traces of painting

- Assessing the effective implementation of the agro-energetic chains that can be obtained as a combination of all the scenarios, excluding those evaluated as impossible;
- Defining the sustainability from the environmental and economical points of view through some specific criteria previously fixed that allow to indicate the more suitable agro-energetic chains;
- Carrying out a more detailed environmental analysis able to investigate additional aspects according to standardized indicators, in order to choose the chain with lower environmental impacts.

As discussed in Chap. 1, all this methodology can be applied at the planning stage or during the development of the feasibility study. Therefore, it is possible to identify as decision makers politicians, technicians and/or farmers basing on the different stages of the decision step.

3.3 Scenarios Definition

Agro-energetic chains based on the reuse of agricultural residues are usually complex and characterised by various steps such as harvesting, processing into biofuel, packaging, transport.

Except from the harvesting phase, all other processes can be arranged in different ways. Particularly, the localisation and the timing of the operations can vary: for instance, the biomass conditioning may occur during the harvesting in field or may constitute a separated phase after the harvesting near the field, in a dedicated area or close to the energy production plant.

Therefore, in order to define all the possible scenarios, at first different solutions for each phase must be considered; then, combining together all the solutions previously identified, several scenarios must be set [19].

In the following, the main implemented solutions are illustrated regarding harvesting, conditioning, packaging, transport and energy conversion, analysing the field operations (i.e. yard characteristics), the logistics (i.e. biomass management and transport conditions) and the energy production phase (i.e. plant typology and its technical characteristics). It is important to highlight that each single choice in a specific phase may affect all the next ones: in fact, the decision concerning the typology of the biofuel produced (e.g. wood logs instead of wood chips) obviously influences the choice of the energy conversion plant discarding all the incompatible solutions.

3.3.1 *Description of Yards*

Regarding biomass harvesting, several possible yards have been defined taking into account usual olive-grove management, typology of operations currently carried out, level of mechanisation, etc. The choice of the most suitable yard for a specific case depends on various factors, such as ground conditions and slope, olive-grove organisation and management, headland size, etc. For instance, if it is needed to operate in terraces, only the more compact machines can be used; if slope is very high (>20%) no mechanisation is possible; whilst, on flat or moderately sloped terrain it is possible to adopt all sorts of equipment. Great attention must also be given to the presence of stones, which can be harvested together with the pruning residues and destroy some mechanical devices; therefore, if the terrain presents this characteristic, it is profitable to use a machine with pick-up utilities.

Moreover, it is also important to investigate the other environmental aspects influenced by the use of machines: for example, if in a specific area the hydrological risk is high, machines with reduced weight must be preferred with the aim to limit the risk and to avoid a more significant soil compaction.

Generally, olive-groves have distance between the trees rows which does not limit the choice of the size of the machines used. However, the presence of areas along the field may be useful to move and temporally store the harvested biomass, allowing a different organisation of the yard and a different choice of the equipment.

In some cases, it is convenient to know which type of management is adopted by the farmer, i.e. the cutting modus and frequency and/or pesticides use, because this information can advise about pruning in terms of diameter dimensions, density per square metre, foliage presence, chemical compounds contained in wood, etc.

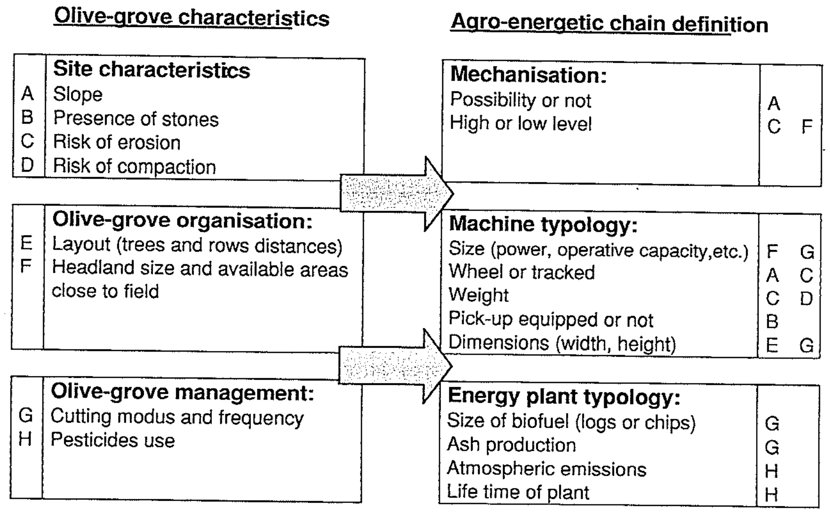

Fig. 3.2 Influence of olive-grove characteristics on different aspects of the agro-energetic chain. A letter (from A to H) has been associated with each characteristic with the aim to highlight by which of these characteristics each chain aspect is influenced

Particularly, the pruning size conditions the yard mechanisation and the harvesting technology: usually, small shredders are able to process branches with a maximum diameter of 5 cm, whilst industrial or forestry chippers are suitable for larger dimensions. In this way, the operative capacity of the yards and the biomass production costs are also fixed.

A consistent presence of foliage in relation to the wood mass (more than 25%), which is usually due to a low frequency of cutting (once a year), influences the reuse of the biomass: if the wood is used in a direct combustion plant, the combustion process will be affected by this characteristic and, for instance, corrosion phenomenon, atmospheric emissions of related compounds and ashes production will arise.

Accurate knowledge of the chemical product used for pest control is useful, even if no reliable experimental tests have been carried out for the absorption of these chemical compounds in wood but only for fruits in order to achieve a sufficient safety level for human health.

Finally, the arrangement of pruning plays an important role in the success of the harvest: to facilitate the work of machines, reduce losses and avoid clogging, pruning residues should be windrowed, taking into account the dimensions (width and height by the ground) of the harvesting machines.

In the scheme below the main olive-grove characteristics that contribute to define the harvesting yards are summarized: particularly, a letter (from A to H) has been associated with each characteristic with the aim to highlight the characteristics that influence the aspects of the agro-energetic chain (Fig. 3.2).

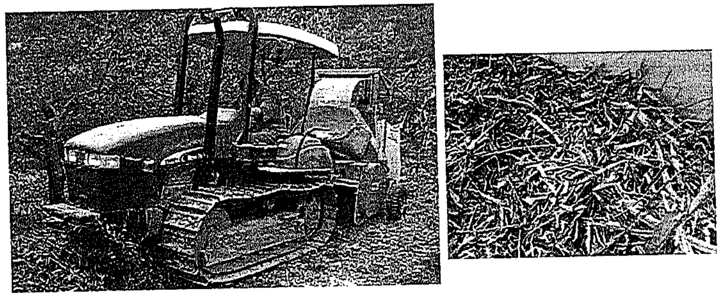

Fig. 3.3 Agricultural shredder equipped with a packaging system in olive-grove

On the basis of the literature [4, 8, 18, 21, 22] it is possible to identify four different techniques and yards to harvest, process and recover olive tree pruning: shredding in the field, shredding or chipping in the headland, baling and industrial harvesting.

Shredding in field is an interesting technique that allows to move the woody biomass from the field in a simplified way, reducing transport costs and improving logistics. Shredders result as a modification of traditional mulchers (see Fig. 3.3), equipped with a device able to collect the shredded residues with a volume variable between 2.0 and 7.0 m^3.

In general, machines have a box or a canvas bag (i.e. big bag) where the processed biomass can be temporally stored or they are able to deliver the product in a trailer alongside. These two different solutions must be carefully evaluated considering site characteristics, because the second requires larger operative areas and lower slopes.

In any case, the required power varies from 40 to 70 kW depending on the model; the maximum diameter treated is about 5 cm. Some machines are equipped with a pick-up: this additional utility allows to work on stony ground and to preserve the shredded wood from any contamination of grass and/or earth. It is possible to achieve an operative capacity of 0.6–0.9 t_{db}/h, with an average cost of 60 €/t_{db}.

Industrial shredders (see Fig. 3.4) are also available on the market; they are obtained by modifying disk or drum chippers, require high power (e.g. 150 kW) and allow to treat branches also with a diameter of 10–15 cm, reaching operative capacities of about 3.0–5.0 t_{db}/h and a corresponding cost of about 40 €/t_{dm}.

Shredding or chipping in the headland implies a traditional organisation of the operations before the harvesting phase: in fact, when pruning residues are not reused as biofuels, they are mulched and left in field or alternatively they are windrowed, moved with tractor equipped with fork (see Fig. 3.5) and finally concentrated in the headland where usually they are burned. Therefore, if shredding or chipping in the headland is proposed, this phase replaces the traditional burning of the residues and all the previous processes are carried out in a similar way.

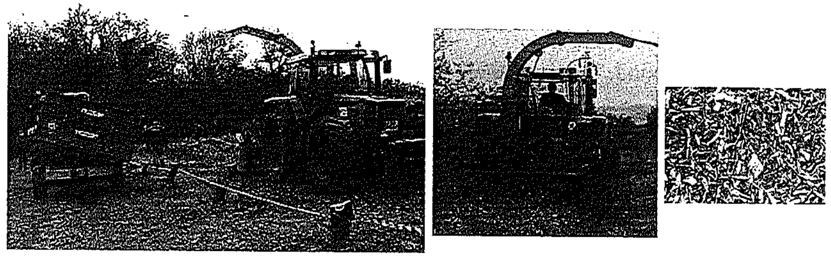

Fig. 3.4 Industrial shredder in olive-grove. From *left* to *right*: delivery of the shredded pruning residues in the rural trailer, machine alimentation, processed biomass

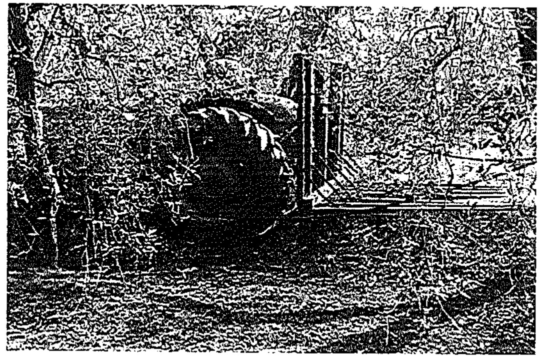

Fig. 3.5 Tractor equipped with fork used to move the pruning from field to the headland

Considering the phase of pruning collection and storage in the headland, an operative capacity of 0.5–0.7 t_{db}/h and a cost of about 60 €/t_{db} may be hypothesised. For the next step the shredding or chipping machine powered with a hydraulic crane is operated by a tractor with a power of 100–120 kW. The operative capacity reached is 2.0–3.0 t_{db}/h with a cost of about 30 €/t_{dm}.

Baling is a processing technique suitable for the thin woody residues difficult to manipulate otherwise. This solution allows to organize the biomass into homogeneous units, and consequently facilitate handling and storage. Machines present on market can be divided into three groups: small rectangular balers, small round balers and industrial balers.

The small rectangular balers are derived by press-fodder machines, packing parallelepiped bales with a plunger device with reciprocating rectilinear motion. They are applied to an agricultural tractor with a power ranging between 40 and 60 kW, able to work on a front of 1.0–1.5 m. Bales have an average size of 45 × 35 × 70 cm; their weight is about 40 kg depending on the moisture of the olive tree pruning collected. The operative capacity is also variable because of several factors (i.e. site characteristics; type, size, moisture of residue; work conditions; etc.) but hypothesising a team of two workers (one driving the tractor and one facilitating the collection with a fork) it may be estimated about

600–1,000 bales/day correspondent to a 1.0 ton of wood on dry basis processed per hour with a production cost of 50 €/t_{db}.

The small round balers actually use the same operating principle of the industrial models, but have a limited size and weight (about 25% of the standard models) in order to be used in fields with a very reduced tree spacing. They can be applied to a small tractor able to supply a power of 25–30 kW. Bales can weight from 30 to 40 kg, depending on the type of material. These machines need only one operator and reach an operative capacity of about 1.6 t_{db}/h, compared to an estimated cost of about 25 €/t_{db}.

Industrial balers used to collect olive tree pruning are also derived from modified farm equipment. In this case the field of application is quite different: these machines can easily and efficiently work only in modern and well-organized plants, because their large size and the yard implemented require operative areas with adequate dimensions.

The diameter of the bales is equal to 1.0–1.5 m with a volume of 1.0–2.0 m^3, depending on the model; the weight per bale varies from 500 to 700 kg depending both on machine model and setting and on type of material collected. All the packaging functions are controlled by a computer directly used by the tractor driver which is able to do all the work alone. These machines can be applied to a tractor of 60 kW and reach an operative capacity of 2.0–4.0 t_{db}/h, with an average production cost of 20 €/t_{db}.

When all the biomass has been harvested and packaged, the bales must be collected from the field, usually through a tractor equipped with fork; in a second phase, the bales can be directly used in adequate kiln or processed in order to obtain a more performed biofuel (e.g. wood chips).

Finally, it is possible to implement industrial harvesting techniques, which allow to perform more processes in only one step and reduce drastically the associated costs.

Theoretically, the same machine can simultaneously perform the four operations required to recover the pruning residues, i.e. cutting, windrowing, conditioning and transport. Commercially, there are already some interesting solutions. For example, round balers equipped with some braches able to windrow, with a small trailer to store and move the bales and eventually also with pruners only in plantations where it is advisable. Another possibility is constituted by shredders (see Fig. 3.6) provided with a multidisc bar applied to a hydraulic arm on the right side of the machine, with a tank mounted on the front under the bar where a conveyor sends the pruning to the shredding chamber, with a grid of calibration to improve product quality and with a posterior tank with a capacity of 10 m^3 where shredded pruning is temporally stored.

Taking into account all the possible yards applicable to the pruning harvesting, it must be highlighted that logistics plays an important role: biomass collection, transport and delivery to the energetic plant must be efficiently organized. In fact, it is possible to implement different scenarios to optimize the biofuel production and management:

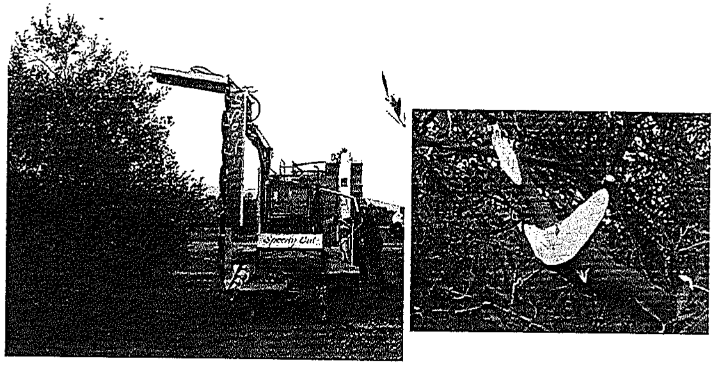

Fig. 3.6 Industrial shredder in olive-grove able to cut, collect, shred and transport the biomass simultaneously. On the right a particular of an olive tree branch after mechanical cutting

- Biomass chipping in field and wood chips delivery to the energetic plant;
- Pruning harvesting and concentration in the headland, biomass chipping in the headland or in other dedicated areas even after a natural drying period, chips use in the conversion plant;
- Bales production and transport to the user, eventual chipping of the bales (this phase can also be avoided if bales are directly used in the burner, i.e. cigar burner), use of the biomass in an energetic plant.

All these scenarios can be realized with several technologies available on the market, at industrial or semi-industrial level, according to different investment costs and different working performances (see Table 3.4).

Yards with high mechanisation levels are more suitable for specialized olive-groves characterised by a management which usually originates a larger quantity of pruning residuals than obtained in traditional plants. In this case the harvesting is carried out in a more efficient way using machines designed for the forestry sector than agricultural equipments. All these solutions present comparable costs for biomass harvesting and treatment only if solutions are correctly chosen considering site characteristics, olive-grove organisation and management. On the other hand, olive-grove with high extension (no field fragmentation) and regular layout with high distance (5–6 m) between rows permit the use of machines with a very high operative capacity able to reduce significantly the production costs.

On the basis of all the previous considerations, eight different scenarios have been fixed, as reported in Table 3.5. For each scenario a brief description of the harvesting yard indicating the machines used, the typology of the produced biomass and the associated costs have been listed. All the processing costs have been referred to a ton of wood on wet basis, considering an average moisture of 35% and have been collected in several references.

All the proposed scenarios provide a previous phase of manual pruning usually followed by windrowing (except for the scenario Y3): Fig. 3.7 illustrates these operations.

Table 3.4 Standard yards for the energetic reuse of olive tree pruning

	Maximum diameter of branches (cm)	Product	Power of tractor(kW)	Yard of wood harvesting	Yard of biofuel collection	Operative capacity (t_{db}/h)	Harvesting cost (€/t_{db})
Shredder in field							
Shredder from modified mulcher	5	Wood chips	40–70	Tractor with shredder One worker	Tractor with trailer One worker	0.6–0.9	55–60
Shredder from modified chipper	10–15	Wood chips	150	Tractor with shredder One worker	Tractor with trailer One worker	3.0–5.0	35–40
Shredder or chipper in the headland							
First phase: pruning collection	–	Wood branches	30–40	Tractor with fork One worker	–	0.5–0.7	50–60
Second phase: wood chipping	20	Wood chips	100–120	Tractor with chipper One worker	–	2.0–3.0	30–35
Baler							
Small rectangular baler	7	Parallelepiped bales, with a size 45 × 35 × 70 cm and a weight of 40 kg for each	40–60	Tractor with baler Two workers	Tractor with trailer Two workers	1.0	45–55
Small round baler	4–5	Round bales, with a weight of 30–40 kg for each	25–30	Tractor with baler One worker	Tractor with trailer Two workers	1.6	20–25

(continued)

Table 3.4 (continued)

	Maximum diameter of branches (cm)	Product	Power of tractor(kW)	Yard of wood harvesting	Yard of biofuel collection	Operative capacity (t_{db}/h)	Harvesting cost (€/t_{db})
Industrial baler	4–5	Round bales, with a diameter of 1.0–1.5 m, a volume of 1.0–2.0 m^3 and a weight of 500–700 kg for each	60	Tractor with baler One worker	Tractor with fork Tractor with trailer Two workers	2.0–4.0	15–25

The operative capacity and the harvesting cost are referred to the woody biomass on dry basis

Table 3.5 Scenarios hypothesised for harvesting and processing the pruning residues in the MCA

Scenarios	Yard mechanisations	Biomass outputs	Biomass treatment costs (€/t_{wb})	References
Y1	Windrower Tractor with fork	No biomass produced (biomass burned)	59.00	[4, 8]
Y2	Windrower Shredder Landfilling	No biomass produced (biomass landfilled)	50.00	[8]
Y3	Shredder with packaging system Tractor trailer	Wood chips	68.00	[8]
Y4	Windrower Shredder Tractor trailer	Wood chips	54.00	[4, 22]
Y5	Windrower Tractor with fork Chipper Tractor trailer	Wood chips	50.50	[4, 22]
Y6	Windrower Baler Tractor trailer	Square bales	13.50	[4, 22]
Y7	Windrower Baler Tractor trailer Chipper at storage	Square bales	45.50	[4, 22]
Y8	Windrower Baler Chipper at storage	Round bales	65.50	[4, 22]

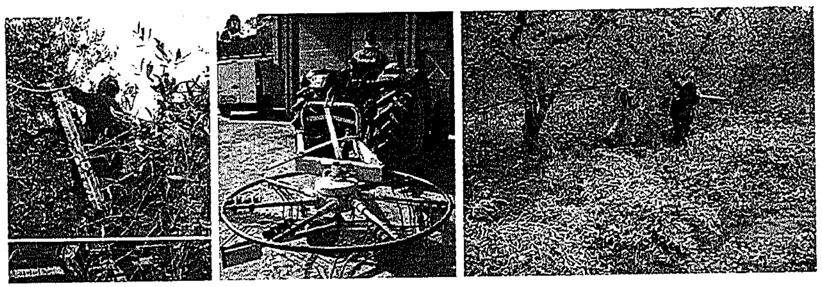

Fig. 3.7 Pruning and windrowing in a Tuscany olive-grove close to Grosseto: manual activities and machine adopted

Particularly; scenarios Y1 and Y2 hypothesise that there is no energetic reuse of the pruning residues. In the first one the biomass is collected in the headland and then burned, even if a large number of Municipalities in Italy forbid this activity through specific laws and regulations. The second one provides the shredding of the pruning residues afterwards left in field and landfilled: this practice is profitable in order to preserve and in some cases increase the organic matter of the soil and the amount of nutrients, but often it is not implemented because of the risk of pests diffusion from tree to tree.

In any case, even if these two scenarios imply a low level of mechanisation, they are not free of charge: the associated costs are similar to those estimated for the other solutions and may also increase for specific site characteristics (i.e. field fragmentation, high slope, low pruning density, reduced operative areas along the field, etc.). Regarding the scenario Y1, it must be highlighted that the biomass treatment cost largely depends on the movement of the wood branches from the field to the headland (see Table 3.4).

Scenarios Y3 and Y4 concern yards able to shred the biomass in field and they only differ for few aspects. Y3 hypothesises the use of a shredder equipped with a packaging system, i.e. big-bags, used for wood chips storage and delivered on field when fulfilled, whilst Y4 adopts a machine which ejects the processed biomass in a rural trailer following the shredder during its activity.

Moreover, Y3 does not require a windrowing phase before harvesting starts, because it is supposed that the machine used here can intercept the pruning passing more than one time into the same row adopting a speed higher than usual. This way to operate is also profitable in order to limit the height of the pruning piles and consequently avoid stops due to machine clogs.

The Y5 scenario also produces wood chips but in this case the biomass is firstly collected using a tractor with fork and then chipped in the headland. In this case, the cost results as lower because the chipper has an operative capacity higher than those of the small shredders adopted in scenarios Y3 and Y4, and because this organisation of the yard allows to avoid or significantly reduce all the additional times (i.e. extra times which must be added to the working time of the machine) due to machine reversing, stopping for technical controls and/or resetting, etc.

Finally, the last three scenarios provide the use of different types of baling machines: in this case, even if the processing costs and the mechanisation level seem lower than those hypothesised for the other scenarios, it must be considered that biomass will be almost certainly chipped in a subsequent phase in order to be used in an energy plant. The Y6 scenario where small rectangular bales are produced presents a very low cost, but whether bales must be chipped in an intermediate phase or can be directly used in a combustion plant with low power, additional costs, higher than these for the other two scenarios, must be taken into account: in the first case chipping will require more extra time due to the alimentation phase and this extra time will be much higher as the bale sizes will be reduced; in the second case the boiler will have a lower efficiency during combustion and much more wood will be required to supply a certain quantity of thermal energy.

Table 3.6 Scenarios hypothesised for logistics in the MCA

Scenarios	First transport (km)	First storage	Second transport (km)	Second storage	Plant typology
L1	0	–	0	–	–
L2	15	Farm storage	0	–	Small-sized
L3	15	Farm storage	40	Plant storage	Medium-sized
L4	15	Farm storage	100	Plant storage	High-sized
L5	0	–	40	Plant storage	Medium-sized
L6	0	–	100	Plant storage	High-sized

In conclusion, all the proposed solutions can be easily implemented in the farms deciding, from time to time, the mechanisation level (and consequently the typologies of machines to be used) and the biomass output. Moreover, the processing costs seem to be comparable with one another and also with solutions that do not provide the reuse of olive tree pruning: this fact is very important to promote the biofuel production from residual materials instead of dedicated crops without causing additional environmental costs (external costs).

3.3.2 Description of Logistics

One of the most important problems in using biomass as a fuel is the spreading out of supplies together with the low territorial density, in comparison with the traditional fossil fuels. In most of the cases the biomass supply is seasonal, namely variable in time, thus creating the need for a temporary stockpiling before and after delivery to the power, heat or processing plant. In addition, storage costs are mainly due to the management of great volumes of biomass, since its low specific weight and need to be stored in large quantities. On the other hand, transport costs are in general mainly dependent on geographic issues [6].

On the basis of these assumptions, different scenarios for biomass transport and storage have been designed. The hypothesis developed is mainly generic because of uncertainty about typology, size and localisation of the energy conversion plants. Particularly, the following scenarios have been defined (see Table 3.6):

1. Scenario L1 does not identify any storage as when pruning are burned along field or landfilled;
2. Scenario L2 hypothesised a reuse of the biomass within the farm for thermal energy production in a small-sized plant. It is important to highlight that this solution does not assure the effective wood utilisation in an appropriate conversion plant characterised by high efficiency, low atmospheric emissions, etc. In fact, farmers could use these biomass in stoves, fireplaces or in heat boilers with an efficiency lower than 70% and without any control technology for the atmospheric emissions;

3. Scenarios L3 and L5 are referred to a medium-sized energy plant which is supposedly located within a distance of 40 km. Particularly, in the first scenario it is also provided an intermediate storage, whilst in the second the biomass is directly delivered to the energy plant;
4. Scenarios L4 and L6 concern high-sized energy plants sited at a distance of about 100 km, respectively, with an intermediate storage at the farm or not.

It is important to highlight that these possible scenarios assume only two different typologies of means of transport: for the biomass movement within the farm a tractor equipped with a rural trailer is used; for the biomass delivery to the plant it is also necessary to utilise highway trucks or similar vehicles. Obviously these two typologies of means have very different characteristics in terms of load capacities, speed, atmospheric emissions; therefore, they imply different environmental and economical performances which may be evaluated. Usually, rural transports imply higher costs due to lower speed and load capacity of the mean; whilst trucks cause higher atmospheric emissions. Moreover, limiting the transport distance assures the diffusion of pollution (i.e. atmospheric emissions and noise) only within a constrained area.

3.3.3 Description of Energy Plants

Concerning the energy utilisation scenarios, different plant typologies have been considered: small-, medium- and high-sized direct combustion plants, able to use the woody biomass with different characteristics (i.e. wood chips or bales).

In general, plants using small bales as biofuels are characterised by low power and no automation for the alimentation phase, whilst wood chips boilers may be small-, medium- or high-sized. A significant exception is represented by high-sized plants which are able to burn large round bales without providing a previous phase of chipping: they are mainly used for herbaceous biomass and equipped with specific burners called "cigar-burners"; they are diffused in Northern Europe, but in Italy they are not yet present.

In Table 3.7, the main typologies of energetic plants for biomass are listed, indicating also some characteristics of the biofuels used in [14].

Moreover, besides price, the main characteristics of a boiler are its power (kW), efficiency (%), service life (years) and user-friendliness or level of automation. In the last 25 years, wood-fed boilers have undergone significant technological improvement.

The highest technological level is observed in small- and medium-sized automatic chip-fed boilers, where there is no need for the presence of a person to manually stoke the fuel.

In the 1980s the average efficiency of wood-fed boilers was about 50–60%, whereas today it exceeds 80–85%, reaching over 90% in the best models. As a positive consequence, emissions have significantly decreased and reliability and comfort have been raised: Table 3.8 shows standard levels of VOC and NO_x emissions for domestic plants which usually are not equipped with specific

Table 3.7 Plants typology for the energetic reuse of the olive tree pruning

Plant typology	Range of power (kW)	Plant automation	Biofuel characteristics		
			Typology	Ash content (%)	Moisture (%)
Wood stove	2.0–10.0	No automation	Wood logs	<2	5–20
Wood boiler	5.0–50.0	No automation	Wood logs	<2	5–30
Pellet stove and boiler	2.0–25.0	Partial automation	Pellets	<2	8–10
Boiler with under stocker furnace	20–2,500	Total automation	Wood chips and residuals	<2	5–50
Boiler with travelling grate furnace	150–15,000	Total automation	Biomass	<50	5–60
Boiler with grate furnace and preheating system of biofuel	20–1,500	Total automation	Woody residuals	<5	5–35
Boiler with under stocker furnace and rotating grate	2,000–5,000	Total automation	Wood chips	<50	40–65
Boiler with cigar burner	3,000–5,000	Total automation	Round bales	<5	20
Boiler with whole bales furnace	12–50	Total automation	Small bales	<5	20
Boiler with fixed bed furnace	5,000–15,000	Total automation	Biomass	<50	5–60
Boiler with circulating fluidised bed furnace	15,000–100,000	Total automation	Biomass	<50	5–60
Boiler with dust firing furnace	5,000–10,000	Total automation	Biomass	<5	20

Table 3.8 Atmospheric emissions of domestic plants for woody biomass [20]

Plant typology	VOC (mg/kWh)	NO_x (mg/kWh)
Traditional wood boiler	1,000	350
Modern wood boiler	300	520
Modern wood stove	700	n.a.
Wood pellet boiler	160	<270
Wood pellet stove	120	<270

abatement systems because of the reduced size. These data are particularly important because airborne emissions constitute a critical aspect mainly for small-sized boilers where low temperatures of combustion, insufficient and non homogeneous air–fuel mix, and frequent stops and starts of the plant can cause emissions about ten times higher than those of industrial plants.

All different scenarios considered in the MCA are described in Table 3.9, reporting also additional information [3, 13, 16, 17] as annual fuel demand, annual

Table 3.9 Scenarios hypothesised for energetic plants in the MCA

Scenario	Plant typology	Operating time (h/year)	Efficiency (%)	Investment costs (k€/kW)	Plant automation
E1	Small-sized (i.e. 20–60 kW) direct combustion plant using small bales for heat production	2,200	70	0.35–0.40	No automation
E2	Small-sized (i.e. 100 kW) direct combustion plant using wood chips for heat production	2,200	85	0.40–0.60	Partial automation
E3	Medium-sized (<1 MW) direct combustion plant using wood chips for heat production	2,200	85	0.15–0.20	Partial automation
E4	Medium-sized (i.e. 1 MW e 150 kW e) direct combustion plant using wood chips for electricity production	5,000	15	3.50–5.00	Complete automation
E5	High-sized (i.e. 10 MW e 3.6 MW e) direct combustion plant using wood chips for electricity production	7,000	20	5.00–7.00	Complete automation

operating time, energy efficiency and investment costs. Particularly, the scenario E1 identifies an energy plant which uses directly the small bales of the harvested pruning, while the other scenarios hypothesise the use of wood chips. In addition, it must be highlighted that the thermal energy production has been preferred and only two scenarios (E4 and E5) adopt plants able to produce electricity through gas turbines; this is also shown by higher annual operating times, lower efficiency values, higher investment costs and higher level of automation of the plant. In fact, woody biomass is more suitable for thermal energy production, also taking into account that power plants present higher size and consequently require higher amounts of biofuels, complicating the relative logistics, implying elevated transport distances and finally determining high environmental pressures and management costs for biomass supply.

3.4 Decision Criteria Identification

For each scenario of biomass harvesting (Y scenarios), logistics (L scenarios) and energy utilisation (E scenarios), some decision criteria and indicators concerning environmental impacts and economical sustainability, have been defined as reported in Table 3.10.

Table 3.10 Definition of evaluation criteria and indicators for bio-energy scenarios (i.e. Y = biomass harvesting and treatment; L = logistics; E = energy utilisation)

Criteria and indicators	Scenario typology	Assigned values A = 1	B = 2	C = 3
Environmental aspects:				
No. of machines used during field operations	Y	1–2	3	4
Distance of transport (km)	L	≤50	>50 and ≤100	>100
Efficiency of the energetic plant (%)	E	≥85	≥50 and <85	<50
Economical aspects:				
Biofuel production cost (€/t)	Y	≤50	>50 and ≤60	>60
No. of storages	L	0	1	2
Plant investment cost (k€/kW)	E	≤0.3	>0.3 and ≤2.0	>2.0
Plant management	E	Complete automation	Partial automation	No automation

Particularly, the decision criteria have been determined taking into account several aspects.

From the environmental point of view, scenarios can be preferred if the number of machines involved for harvesting is reduced and mechanisation level is low, if transport distances are limited, if the energy plant has high conversion efficiency. Moreover, economical benefits are possible if the costs of biofuel production and treatment are limited, if the storage operations are reduced, if the investment costs for the energy plant are limited and if the management of the energy plant is easy with high level of automation (low number of workers, few specialized workers needed, etc.).

Concerning the proposed environmental criteria it is necessary to explain the choices made. The methodology described in this book provides as a first step the application of an MCA and, only in a second step, of a more specific approach with the aim to detect additional environmental pressures. As illustrated in Chap. 1 the second step is carried out implementing the LCA and measuring only two environmental impacts, the CO_2 equivalent and the CER for the more suitable scenarios identified through the MCA. These two indicators are very important for the agro-energetic chains hypothesised which provide the reuse of the olive tree pruning as biofuels, because they allow to evaluate the performances of the different scenarios at a global level in terms of GHG savings considering also the energy efficiency. In contrast, this approach must be considered as a complementary tool of the assessment carried out through the MCA where other impacts on the territory have been considered in order to evaluate the effects of the described operations at a local scale.

In fact, usually the environmental impacts of agriculture at a local level can be evaluated adopting an Environmental Impact Assessment (EIA) and selecting a specific group of pressure indicators which are ideally assessed for each environmental zone. The main pressure indicators used are erosion, soil compaction, nutrient leaching to groundwater and surface water, pesticide pollution of soils and water, water abstraction, fire risk, biodiversity [11]. In addition, for olive-groves it is also important to consider the possible effects related to landscape modifications.

Different pruning managements can indirectly modify these pressures. For instance, concerning pruning management it is possible to highlight that

- Reduced mechanisation of the harvesting phase may limit the compaction and erosion problems;
- Chipping and landfilling the pruning residuals is a good technique to increment the organic matter in soil, increasing its fertility and reducing the erosion;
- Limiting the soil compaction allows a better infiltration of the water in the soil, reducing the run-off phenomena and irrigation needs (trees are able to use the water absorbed by the ground);
- Burning of pruning residues causes some air pollution and fire risk.

Besides, all these assumptions have been indirectly considered when the environmental criteria of the MCA have been fixed. In fact, it is possible to affirm that a reduced number of machines corresponds to a low mechanisation level and consequently assure a lower risk of erosion and compaction of the soil, which is affected by lower machine weights and passages. In this way it is also possible to increase the possibility of grass and weeds diffusion which are able to contrast these phenomena and promote a biodiversity preservation. Moreover, avoiding the compaction of the soil guarantees a better absorption of rainfall and consequently reduces irrigation needs, i.e. water consumption. In addition, a limited transport distance implies shorter trips of transport means and so lower pollution due to atmospheric emissions and noise affect the territory.

Finally, for the energy plants the global efficiency has been taken into account: this choice is based on the indications of the recent guidelines of the EC about the environmental sustainability of solid biofuels [10]: it is important to know how the biofuels are used during the conversion energy phase because the higher the energy efficiency of the conversion, the higher the fossil fuel savings and the lower the required quantity of the biofuel and the impacts due to its production.

Taking into account a planning stage or developing a feasibility study, the costs analysis can be done with a very limited accuracy level. In general few data are available in these phases, therefore several information collected by the literature are used avoiding to develop detailed calculations. Table 3.10 reports as a first criterion the evaluation of the biofuel production cost, assuming that the best values are those less than 50 €/t_{wb}. This limit is imposed by the market where wood chips are sold at about 30–40 €/t_{wb} at the high-sized energy plants.

Moreover, also the storage cost must be considered because not only logistics is more complicated but also indirect costs are required: for example, additional biomass treatment may be needed in order to guarantee the biomass conservation for a longer period (i.e. some woody biomass with high moisture content can be previously dried reducing the risk of fermentation phenomenon).

Regarding the conversion phase, it is necessary to specify that only investment costs of the energetic plants have been considered, because usually in Italy one of the main barriers against diffusion of the biofuels is the initial investment even if it is possible to use public financing and/or taxes reduction.

In any case also the management costs of the plants have indirectly been considered: in fact the higher the level of automation, the lower the costs.

3.5 Values and Weight Associated with the Criteria

For each criterion a specific weight has been fixed, as reported in Table 3.11.

The weights are numerical and allow to calculate for each scenario the environmental and the economical sustainability separately as weighted means associating to each criterion the corresponding value (see Sect. 3.4) multiplied for its weight.

No suggestions are supplied in order to determine which sustainability is more important between the environmental and the economical one, because they are not comparable from a technical point of view but only from a political one. If decision makers or planners decide to promote one sustainability in respect to the other an additional weight can be introduced to differentiate the contribution of these two factors within the calculation of the global value.

Between the environmental criteria and the associated indicators the efficiency of the energetic plants has been classified as the most important (two times more important than others) characteristic following the indication in [10]. Particularly, the EC decided to introduce this criteria according to the objectives of the RED where the utilisation of the renewable sources (+20% within 2020) has been contemporarily promoted with the increase in energy efficiency (+20% within 2020). On the other hand between the economical criteria and the associated indicators the biofuel production cost has been evaluated as the most significant one (two times more significant than others), because the literature [4, 6, 8, 13, 22] indicates that this aspect is the most critical in order to decide if the agro-energetic chain is convenient or not in respect to the energy production through fossil fuels.

3.6 Results of the MCA for All Possible Agro-Energetic Chains

For each scenario illustrated in Sect. 3.3 for harvesting, logistics and energetic conversion, the judgements have been calculated applying the environmental and the economical criteria, as reported in Tables 3.12, 3.13 and 3.14.

Particularly, it can be highlighted that for the harvesting yards the best scenarios determined by the environmental criteria do not correspond to the best scenarios identified from the economical point of view: in fact, yards with lower mechanisation level have been considered as more environmentally sustainable

Table 3.11 Weights for sustainability criteria and indicators in order to calculate the global score of each proposed scenario

Criteria and indicators	Weights
Environmental aspects:	
No. of machines used during field operations	0.25
Distance of transport (km)	0.25
Efficiency of the energetic plant (%)	0.50
Total	1.00
Economical aspects:	
Biofuel production cost (€/t)	0.40
No. of storages	0.20
Plant investment cost (k€/kW)	0.20
Plant management	0.20
Total	1.00

Table 3.12 Results obtained applying the MCA to the proposed yards illustrated in Sect. 3.3

Scenarios	Environmental scores	Economical scores
Y1	**A = 1**	B = 2
Y2	B = 2	**A = 1**
Y3	**A = 1**	C = 3
Y4	B = 2	B = 2
Y5	C = 3	B = 2
Y6	B = 2	**A = 1**
Y7	C = 3	**A = 1**
Y8	B = 2	C = 3

The best scenarios are in bold

Table 3.13 Results obtained applying the MCA to the logistics illustrated in Sect. 3.3

Scenarios	Environmental scores	Economical scores
L1	**A = 1**	**A = 1**
L2	**A = 1**	B = 2
L3	B = 2	C = 3
L4	C = 3	C = 3
L5	**A = 1**	B = 2
L6	B = 2	B = 2

The best scenarios are in bold

Table 3.14 Results obtained applying the MCA to the energy plants hypothesised in Sect. 3.3

Scenarios	Environmental scores	Economical scores
E1	B = 2	B = 2 C = 3
E2	A = 1	B = 2 B = 2
E3	A = 1	**A = 1** B = 2
E4	C = 3	C = 3 **A = 1**
E5	C = 3	C = 3 **A = 1**

The best scenarios are in bold

Table 3.15 List of possible agro-energetic chains and results obtained applying the MCA to the proposed scenarios

Chains	Scenarios			Results without weights			Results with weights		
				Environmental scores	Economical scores	Global scores	Environmental scores	Economical scores	Global scores
1	Y1	L1	–	–	–	–	–	–	–
2	Y2	L2	–	–	–	–	–	–	–
3	Y3	L2	E2	1.00	2.25	1.625	1.00	2.40	1.700
4	Y3	L3	E3	1.33	2.25	1.792	1.25	2.40	1.825
5	Y3	L3	E4	2.00	2.50	2.250	2.25	2.60	2.425
6	Y3	L5	E3	1.00	2.00	1.500	1.00	2.20	1.600
7	Y3	L5	E4	1.67	2.25	1.958	2.00	2.40	2.200
8	Y4	L2	E2	1.33	2.00	1.667	1.25	2.00	1.625
9	Y4	L3	E3	1.67	2.00	1.833	1.50	2.00	1.750
10	Y4	L3	E4	2.33	2.25	2.292	2.50	2.20	2.350
11	Y4	L5	E3	1.33	1.75	1.542	1.25	1.80	1.525
12	Y4	L5	E4	2.00	2.00	2.000	2.25	2.00	2.125
13	Y4	L4	E5	2.67	2.25	2.458	2.75	2.20	2.475
14	Y4	L6	E5	2.67	2.00	2.333	2.75	2.00	2.375
15	Y5	L2	E2	1.67	2.00	1.833	1.50	2.00	1.750
16	Y5	L3	E3	2.00	1.75	1.875	1.75	1.80	1.775
17	Y5	L3	E4	2.00	2.25	2.125	1.75	2.20	1.975
18	Y5	L5	E3	1.67	1.75	1.708	1.50	1.80	1.650
19	Y5	L5	E4	2.33	2.00	2.167	2.50	2.00	2.250
20	Y5	L4	E5	3.00	2.25	2.625	3.00	2.20	2.600
21	Y5	L6	E5	3.00	2.00	2.500	3.00	2.00	2.500
22	Y6	L2	E1	1.67	2.00	1.833	1.75	1.80	1.775
23	Y7	L2	E2	1.67	1.75	1.708	1.50	1.60	1.550
24	Y7	L3	E3	2.00	1.75	1.875	1.75	1.60	1.675
25	Y7	L3	E4	2.67	2.00	2.333	2.75	1.80	2.275
26	Y7	L5	E3	1.67	1.50	1.583	1.50	1.40	1.450
27	Y7	L5	E4	2.33	1.75	2.042	2.50	1.60	2.050
28	Y7	L4	E5	3.00	2.00	2.500	3.00	1.80	2.400
29	Y7	L6	E5	3.00	1.75	2.375	3.00	1.60	2.300
30	Y8	L3	E3	1.67	2.25	1.958	1.50	2.40	1.950
31	Y8	L3	E4	2.33	2.50	2.417	2.50	2.60	2.550
32	Y8	L5	E3	1.33	2.00	1.667	1.25	2.20	1.725
33	Y8	L5	E4	2.00	2.25	2.125	2.25	2.40	2.325
34	Y8	L4	E5	2.67	2.50	2.583	2.75	2.60	2.675
35	Y8	L6	E5	2.67	2.25	2.458	2.75	2.40	2.575

but, on the other hand, using a limited number of machines and/or machines characterised by low power, low weight and, in conclusion, low operative capacity, imply higher costs.

On the other hand, logistics which present high environmental sustainability are often also the most convenient solutions from the economical point of view. In fact, minimizing the transport distances significantly reduces the associated environmental pressures (i.e. atmospheric emissions and noise produced by means)

Table 3.16 Six best agro-energetic chains identified through the MCA with or without the application of the weights

Results of the MCA			
Without weights Chains	Values	With weights Chains	Values
6 : Y3–L5–E3	1.500	26 : Y7–L5–E3	1.450
11 : Y4–L5–E3	1.542	11 : Y4–L5–E3	1.525
26 : Y7–L5–E3	1.583	23 : Y7–L2–E2	1.550
3 : Y3–L2–E2	1.625	6 : Y3–L5–E3	1.600
8 : Y4–L2–E2	1.667	8 : Y4–L2–E2	1.625
32 : Y8–L5–E3	1.667	18 : Y5–L5–E3	1.650

but usually also the costs, both directly (lower distances) and indirectly (less number of storages and intermediate movements of the biomass).

Finally, concerning the energy plants it is not so easy to establish a correspondence between environmental and economical criteria, because it is necessary to distinguish between thermal and power production: in general, it is possible to detect the higher efficiencies the higher automation level and investment costs.

Table 3.15 shows the possible agro-energetic chains obtained combining all the proposed scenarios and the relative judgements calculated applying the environmental and the economical criteria, either without or with the weights described in Sect. 3.5. The application of the weights changes the group of the best chains selected through the MCA as highlighted for the first six chains in Table 3.16. Particularly, two chains (3 and 32) are identified as profitable applying the MCA without weights, but not if weights are introduced: in this case other two solutions are more interesting, i.e. chains 23 and 18. Moreover, it is possible to analyse that the results do not identify specific yard scenarios but indicate scenarios L2 and L5 for logistics and scenarios E2 and E3, as the most suitable for the fixed criteria. Therefore, on the basis of the results, scenarios that provide only one transport are preferable and direct combustion plants for thermal energy production (small or medium sized) are identified as the most convenient for the specific typology of biofuel.

3.7 Application of the LCA to the Chains Selected Through the MCA

As explained in the previous paragraphs, for the environmental evaluation, it is needed to distinguish between local and global pressures that the agro-energetic chains may originate. For the first ones it is necessary to take into account the principles on which the EIA is based; for the second ones the LCA methodology is needed according to the recent indications of the EC [10].

The LCA methodology has been applied to the chains identified trough the MCA including the weights illustrated in the paragraph for the environmental and the economical criteria, i.e. chains 6, 8, 11, 18, 23 and 26, in order to determine which of these are more suitable to reduce the environmental pressures.

The inventory phase has been conducted as illustrated in Table 3.17 and all the collected data have been implemented in the software GEMIS 4.5 [15].

Concerning the diesel fuel used in the agricultural machines, it has been hypothesised an LHV of 11.86 kWh/kg and a density of 0.8 kg/l; the LHV of wood has been fixed equal to 3.154 kWh/kg. The quantity of diesel fuel required during field operations has been estimated considering an average utilisation of 60% of the nominal power of the machine and a specific fuel consumption of 0.25 kg/kWh [8, 12]. The atmospheric emissions calculated for the yards are referred only to the direct emissions originated by the machines during operations.

Particularly, chain 6 adopts the shredder Nobili of 60 kW with a packaging system; chains 8 and 11 utilise the shredder Berti of 80 kW followed by rural trailer along the field; chain 18 implements a yard with the chipper Pezzolato of 44 kW derived from the forestry sector; chains 23 and 26 hypothesise the use of the small baler Lerda of 50 kW and a next phase of wood processing is carried out by the chipper Pezzolato of 44 kW.

Transports have been modelled considering that local transports within the farm are carried out with a tractor equipped with a rural trailer whilst the other provide the use of highway trucks. Basing on the data of the software GEMIS for the L2 scenario has been considered the process "truck+semi-trailer-D-rural" with a pay load of 25 t and 94.912 gCO_2/t km of emissions; whilst the L5 scenario corresponds to the process "truck-highway-EURO 4-20-28 t" with 132.64 gCO_2/t km of emissions according to the European emission standard EURO 4.

For the energy conversion phase each hypothesised plant has been characterised by the operation time, the life time, the power, the efficiency, the electricity required by the plant and the main construction materials. In addition, the energetic plants are equipped by a multicyclone to depurate the flue gases assuring a reduction of about 92% of particulate.

The obtained results are reported in the followings. Particularly, chain 18 is the most suitable because it is able to minimize the impacts analysed trough the LCA, i.e. the CO_2eq and the CER (see Chap. 1). However, the MCA has identified chain 18 only as the sixth between the most appreciable ones, also if only the environmental criteria are taken into account without combining them with the economical ones. This is only an apparent contrast because actually the criteria introduced trough the LCA are not taken into account in the MCA and therefore must be evaluated as additional (Figs. 3.8, 3.9).

Considering that the contributions to the CO_2 equivalent emissions (and also to the CER) of logistics and energetic conversion scenarios are about constant from chain to chain, it is obvious that the harvesting and processing phases can make the

Table 3.17 Inventory data for the most sustainable chains according to the MCA

Chain	6	8	11	18	23	26
Harvesting scenarios	Y3	Y4	Y4	Y5	Y7	Y7
Operative capacity (t/h)	0.6	0.9	0.9	2.0	3.0 (baler) 2.0 (chipper)	3.0 (baler) 2.0 (chipper)
Fuel consumption (kg/h)	9	12	12	6.6	7.5 (baler) 6.6 (chipper)	7.5 (baler) 6.6 (chipper)
Operation time (h/year)	1.67	1.11	1.11	0.50	0.83	0.83
Life time (year)	20	20	20	20	20	20
Fuel quantity (kWh/kWh)	0.0564	0.0501	0.0501	0.0124	0.0218	0.0218
CO_2eq emissions (g/MWh)	14,910	13,253	13,253	3,280	5,765	5,765
Logistic scenario	L5	L2	L5	L5	L2	L5
Means typology	Highway truck	Tractor + rural trailer	Highway truck	Highway truck	Tractor + rural trailer	Highway truck
Transport distance (km)	40	15	40	40	15	40
Energetic scenario	E3	E2	E3	E3	E2	E3
Operation time (h/year)	2,200	2,200	2,200	2,200	2,200	2,200
Life time (year)	15	10	15	15	10	15
Power (MW)	0.8	0.1	0.8	0.8	0.1	0.8
Efficiency (%)	85	85	85	85	85	85
Electricity from grid (kWh/kWh)	0.02	0.02	0.02	0.02	0.02	0.02
Metal/Steel (kg/MW)	0.50	0.50	0.50	0.50	0.50	0.50

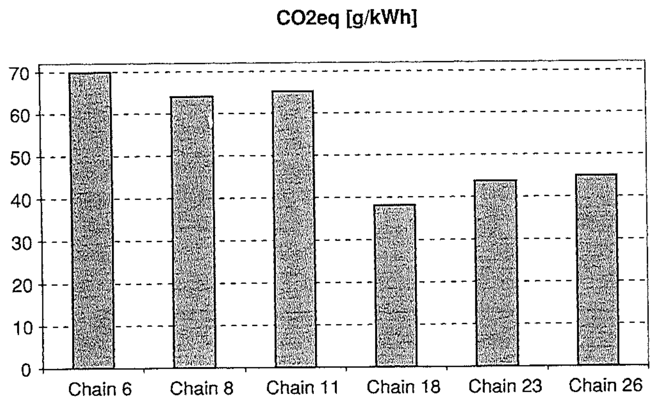

Fig. 3.8 CO_2eq emissions for the most suitable chains identified trough the MCA

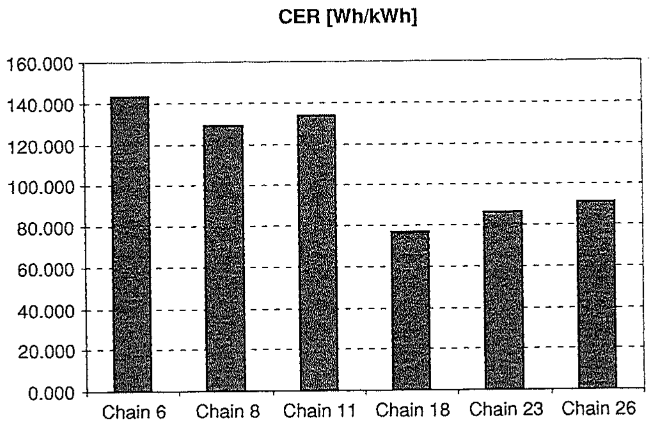

Fig. 3.9 CER for the most suitable chains identified trough the MCA

Table 3.18 CO_2eq emissions for the most suitable chains identified through the MCA

		Chain 6		Chain 8		Chain 11		Chain 18		Chain 23		Chain 26	
Total	gCO_2/kWh	*69.874*		*64.129*		*65.359*		*38.267*		*43.794*		*45.025*	
Y scenario	gCO_2/kWh	Y3	41	Y4	36	Y4	36	Y5	9	Y7	16	Y7	16
L scenario	gCO_2/kWh	L5	2	L2	1	L5	2	L5	2	L2	1	L5	2
E scenario	gCO_2/kWh	E3	27.4	E2	27.6	E3	27.4	E3	27.4	E2	27.6	E3	27.4

Table 3.19 CER for the most suitable chains identified through the MCA

	Chain 6	Chain 8	Chain 11	Chain 18	Chain 23	Chain 26
W/kWh	*143*	*129*	*134*	*77*	*87*	*91*

difference on the total amounts. Particularly, it is possible to highlight (see Tables 3.18 and 3.19) those chains where the Y scenarios results as less pollutant are the best: this is the case of chains 18, 23 and 26 in comparison with the solutions 6, 8 and 11 which present values of indicators also more than four times higher.

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Chapter 4
Agricultural and Forestry Mechanization

4.1 Introduction

In recent years, reducing the environmental impact has become an increasingly important subject for the general public. The objectives imposed by the Kyoto Protocol regarding the reduction of greenhouse gas emissions have guided many research projects towards the supply of alternative "clean" energy that does not come from fossil sources.

In Europe, "20-20-20" programmatic objectives have been set for 2020, i.e. 20% reduction in greenhouse gas production, 20% increase in the use of alternative energy sources in our final energy consumption and, finally, 20% increase in energy efficiency for transformation processes.

Within the context of renewable energy, over the next few years the wood biomass sector predicts that there will be a broad potential for development due to the abundance of raw materials available as well as the simplicity of using the same. In Italy, currently the main sources of wood biomass are from woodland management, farming residue, dedicated crops and, finally, waste matter from agro-industrial processes.

According to the last 2009 biomass energy report [7] Italy has a total installed biomass power capacity of 7,558 MWt, contributing 5.2 Mtep to our country's primary energy production, which corresponds to around 2.7% of our total energy requirements, putting us in the fifth place amongst European countries for the production of energy from agro-forestry biomasses.

The most widespread and commonly used biomasses are: firewood, which is generally used in small stoves for residential use with low output, for the direct production of heat or to supplement the heating system of individual residential units or buildings consisting of several units; chips, used in high conversion efficiency boilers with maximum power capacity of 1 MWt used in a similar way and, finally, pellet stoves, over 1 million of which were installed in Italy in 2009, making our country the top European nation for this type of installation [7].

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