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Agricultural crops and residues as feedstocks for non-food products in Western Europe

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Abstract

New developments in various scientific areas, the increasing consumer concerns with the environment, and significant trends in environmental and agricultural policy developments have resulted in the increase of the range of potential products based on agricultural raw materials. The present paper constitutes the first step of the investigation of the optimal use of indigenous biomass for energy and materials in Western Europe (European Union + EFTA, European Free Trade Area), focusing on the assessment of biomass potential from agricultural crops and residues. A number of crops, industrial and traditional, have been analysed in terms of current production, yields, input requirements, production costs and end uses. These data will form the basis of calculations aiming to identify the most promising agricultural systems for non-food biomass uses in the long term.

Keywords: Industrial crops; Non-food uses; Western Europe; Land use

1. Introduction

Although the dominant role of agriculture is food production, a part of agricultural land has always been devoted to non-food production. In recent years, agriculture is increasingly considered as a source of non-food products, mainly within the framework of emerging technologies, e.g. biotechnology. Such uses include the production of bioenergy and various biomaterials (e.g. fibres, lubricants, bioplastics, speciality and bulk chemicals, etc.) from old and new industrial crops (e.g. oil and starch crops, sorghum, miscanthus) and agricultural residues (e.g. cereal straws). At the European Union (EU) level, such uses have to be taken under serious consideration within the debate of the most promising strategies for cost-effective CO_2 emission reduction in the long run (Gielen et al., 1998). Since biomass availability in Western Europe is limited by a number of factors, including land availability, food consumption and biomass yields per hectare, the limited agricultural resources need to be optimally allocated.

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The objective of this paper is to evaluate a number of established as well as new crops as non-food sources and to highlight their current production and use in Western Europe[1]. The results will assist the analysis of the optimal use of agricultural biomass for energy and materials 'from cradle to grave' in Western European economies, in order to achieve cost-effective greenhouse gas emission reduction on the long term (period 2000–2050).

The crops discussed in this paper can be divided into the following categories.

- Conventional agricultural crops, such as wheat, maize, potato, sugar beet, sunflower and rape
- New industrial crops, such as sweet sorghum and miscanthus.
- Agroforestry crops, i.e. eucalyptus, poplar and willow.

All these crops are of high interest as far as they can fulfil simultaneously the two most important functions of the European agricultural sector (Fischler, 1998), i.e. to provide consumers with healthy and high-quality food products, and protect the environment.

2. Methodological approach

The selection of crops to be included in this assessment has been based on data for the current situation (area cultivated, yield, production capacity, potential for improvement) and foreseeable major changes (set aside land schemes, subsidies, etc.) within the Western Europe agricultural sector. Furthermore, the selection of new industrial and agro-forestry crops was based on additional criteria such as high yields, efficient water use, high dry matter contents at time of harvest, high energy density (MJ/kg) and lowest possible environmental impacts (El Bassam, 1998).

Because of the existing significant differences and variations in crop types, biomass growth rates, labour costs, as well as market conditions, Western Europe has been split into three regions, i.e. North Europe (Denmark, Sweden, Finland and Norway), Middle Europe (Austria, France, Germany, Belgium, Luxembourg, the Netherlands, Ireland, UK and Switzerland) and South Europe (Portugal, Spain, Italy and Greece). The boundaries of these regions coincide with national boundaries in order to connect to national statistics.

The crops grown on the agricultural land of the Northern region are not included in this analysis. The agricultural land areas of the Northern region constitute only 6.5% of the total agricultural land of Western Europe, thus its exclusion from the analysis is not expected to influence the results.

All the conventional crops selected are presently cultivated, both in Middle and South Europe. However, the agricultural sector of South Europe is not so productive (e.g. the average yields of wheat and potato are 6.4 and 6.8 dry tonnes per hectare in Middle Europe, respectively, to be compared with 2.0 and 3.9 dry tonnes per hectare in South Europe). For this reason, the assessment of conventional crops focuses on the Middle region; whereas the assessment of the industrial and agro-forestry crops focuses on South Europe, where these crops may be a valuable alternative. Finally, some crops (miscanthus, poplar and sugar beet) were evaluated in both regions as they have similar yields.

The assessment of current physical flows of the main Western European agro-bioresources and uses (food and non-food) can only be based on a wide range of data. The required data can be split into the following categories.

- Primary data.
- Input data.
- Economic data.

2.1. Primary data

Data included in this set are land area cultivated with each crop, yield of each crop and current production. These data for all conventional crops are available from several national and/or international organisations such as Food and Agriculture Organisation (FAO), EUROSTAT and the National Statistical Offices. This paper was based on data from FAO statistics. The reliability of FAO's data, which is a

[1] The term Western Europe refers to all the EU-15 members, Norway and Switzerland.

critical factor for this analysis, cross-checked with the data from the other sources, revealed only very small differences in a few cases.

Most of the industrial and agro-forestry crops are cultivated in Western Europe in relatively small areas, mainly for experimental purposes. Thus, the collection of data for these crops was based on a literature review as well as personal communications with experts. The same sources of information were used to assess the yields of all the conventional crop residues.

Finally, data on crop yields for the period 1970–1995 (with 5-year intervals) were used to predict the future yields of agricultural crops.

2.2. Input data

This set of data includes nitrogen fertiliser requirements, energy inputs, and labour requirements.

Most of these data are related to the achieved yields and to various site-dependent factors, such as climate (e.g. precipitation amount and distribution) and soil (e.g. soil texture). Thus, in most cases, a range of values is reported. Data presented in the paper were mainly obtained from the literature and, in some cases, through discussions with experts.

2.3. Economic data

Biomass production costs include land rent, establishment of the plantation, machinery, inputs (fuel, fertiliser, etc.), transport, etc. All these costs are site dependent and, as such, cannot be presented by a single value. Furthermore, the scarcity of literature data did not allow precise estimation of production costs.

The estimation of production costs was based on data on:

1. producer prices for each crop; these values include, both, production costs and producer profits, and were used as upper limits of production costs; and
2. the share of inputs in production costs, which represents the proportion of all the inputs required for growing a crop. The values obtained when multiplying producer prices by the percent share of inputs in the total costs were used as lower limits of production costs.

Production cost figures of industrial and agro-forestry crops are based either on model calculations or on data reported from experimental plantations.

3. Results

3.1. Current production and use of biomass

For the purpose of this paper, the term biomass refers only to crops cultivated on agricultural land and their residues, although several other types of biomass exist (wood, residues from the forest industry, animal manure, sewage, etc.)

Table 1 presents the primary and input data for the selected crops. Among these crops, in terms of cultivated area, wheat grain is by far the dominant cultivated crop (9.9 Mha or 12% of the total agricultural land in Middle Europe), followed by rape and maize (2.5 and 2.2 Mha, respectively).

In terms of production, the situation is at first sight misleading. On a fresh matter basis, sugar beet comes first (82.8[2] M fresh t) followed by wheat and potato (68.2 and 34.6 M fresh t, respectively). On a dry matter basis, the dominant crop is wheat (61.4 M dry t) followed by maize and sugar beet (15.8 and 12.3 M dry t, respectively). This ranking remains the same when crop residues are taken into account.

Conventional crop residues constitute another important source of biomass. The estimated available quantity of residues, based on both the cultivated area of each crop and the respective product/residue ratio for each one, is 76.5 M dry t per year (Table 2). A fraction of this amount cannot be exploited mainly for economical reasons (e.g. high cost of harvesting and transportation). According to Panoutsou (1998), the total amount of agricultural residues in the EU is ≈ 153 M dry t.

Fig. 1 presents the main uses of each conventional crop examined. As expected, the dominant

[2] The figure refers only to Middle Europe.

Table 1
Primary and input data for selected crops (1995)[a]

Crop/tree	Area (Mha)	Production (M fresh t)	Yield[b] (dry tonnes per hectare)	N inputs (kg N per hectare)	Energy inputs (GJ per hectare)	Labour (man-hours per hectare)	Energy content (GJ per dry tonne)	By-product
Middle Europe								
Wheat	9.9	68.2	4.6–7.7 (6.4)	100–180	120[c]	17.2	16.5	Straw
Maize	2.2	17.1	6.3–8.0 (7.2)	110–160	120[c]	17	16.5	Cobs and stovers
Sunflower	1.0	2.2	1.8–2.0 (1.9)	50–75	80[c]	16	16	Straw, heads
Rape	2.5	7.5	2.7–4.5 (3.0)	50–100	80[c]	13.9	18.2	Straw
Sugar beet	1.5	82.8	6.5–10.0 (8.2)	55–110	7.4	41.4	15	Tops and leaves
Potato	1.0	34.6	5.4–8.2 (6.9)	75–110	7.4	45.8	15	Tops and leaves
Miscanthus	–	–	20.0–21.0 (20.3)	75	7.4	15	17	–
Poplar	–	–	9.0–12.0 (10.0)	50	6.7	24	17	–
Willow	0.018	–	5.0–20.0 (10.0)	70	6.7	24	17	–
South Europe								
Sugar beet	0.5	23.3	6.5–9.8 (7.4)	55–110	7.4	41.4	15	Tops and leaves
Miscanthus	–	–	22.0–26.0 (23.6)	75	7.4	15	17	–
Sweet sorghum	–	–	22.0–45.0 (35.0)	75–125	9.7	13.4	17	–
Poplar	–	–	6.0–10.0 (8.0)	75	7.4	24	17	–
Eucalyptus	0.5	–	10.0–25.0 (16.0)	75	6.7	24	18	–

[a] Data from Rexen and Munck (1984), Spirinckx and Ceuterick (1996), European Commission (1997b), Smith et al. (1997), Venendaal et al. (1997), Rexen (1998) and FAO.

[b] Values in parentheses refer to average yields.

[c] Energy inputs for wheat, maize, sunflower and rape are in l diesel per hectare.

use of agricultural biomass is in food production. About 55 M fresh tonnes per year are directly used for human consumption (Fig. 2); almost an equal amount of biomass (51 M fresh tonnes per year) is presently used as animal feed to support meat production for human consumption, with the remaining 10.5 M fresh tonnes per year being used for various industrial purposes.

Currently, the EU is self-sufficient in many agricultural products as a result of the Common Agricultural Policy (CAP), which has promoted an intensive farming model. The reform of the CAP in 1992 encouraged the use of agricultural areas for the production of non-food crops (e.g. cultivation of non-food crops on set-aside land with full premium). Thus, the amount of biomass

Table 2
Yields and potential production of residues from agricultural crops (Diamantidis and Koukios, 1998)[a]

Crop	Residue	Residues yield (dry tonnes per hectare)	Potential production (M dry tonnes per hectare)
Wheat (M)	Straw	3.5	34.2
Maize (M)	Cobs, corn stover	9.4	20.7
Rape (M)	Straw	3.0	7.4
Sunflower (M)	Straw, heads	6.0	6.2
Potato (M)	Tops and leaves	2.1	2.1
Sugar beet (M)	Tops and leaves	4.1	6.3
Sugar beet (S)	Tops and leaves	3.7	1.9
Total			78.6

[a] M, Middle Europe; S, South Europe.

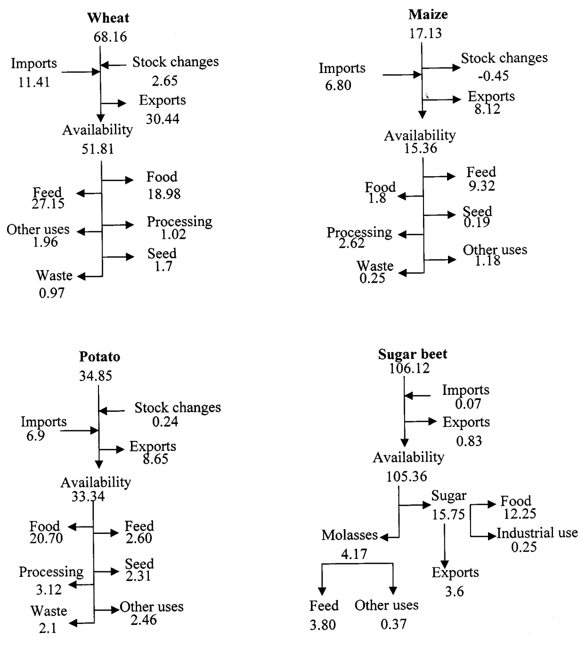

Fig. 1. (a) Flow charts of current production (M fresh tonne per year) and use of wheat, maize, potato and sugar beet in Middle Europe* (1995; FAO). (b) Flow charts of current production (M fresh tonne per year) and use of rape and sunflower in Middle Europe (1995). *Additional notes: the term Western Europe refers to all the EU-15 members, Norway and Switzerland; the figure refers only to Middle Europe; the values for sugar beet refer to Middle and South Europe.

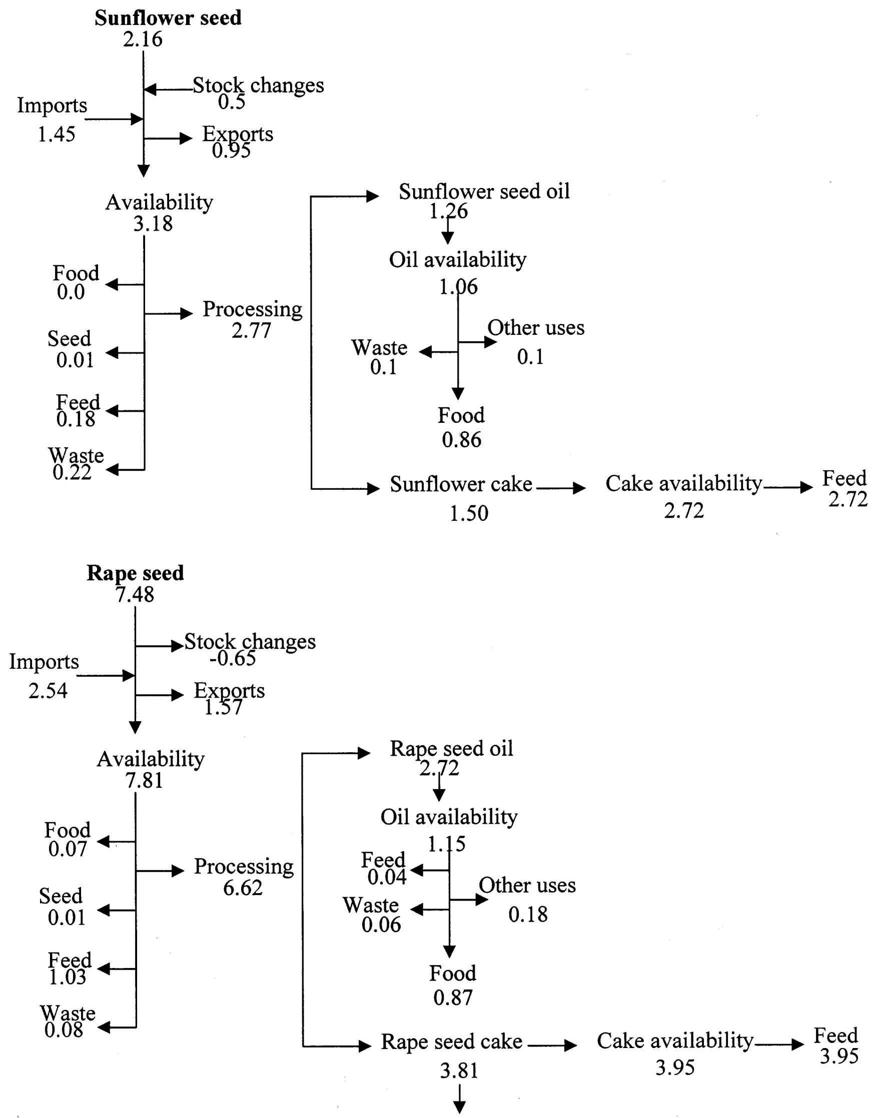

Fig. 1. (*Continued*)

used for energy or material production may increase in the following years. However, the extent to which non-food crops will be introduced does depend on land availability, which will be determined by several factors including agricultural productivity, trade balance, the Western European demand for agricultural products affected by population and the consumption pattern.

3.2. *Current and projected yields of selected crops*

The average yields (1995) of all crops considered are shown in Table 1. Among these crops, the industrial ones have the highest yields. Although these yields have been achieved in experimental plantations where optimal levels of inputs are normally applied, they do not represent the physiological limits of present varieties (El Bas-

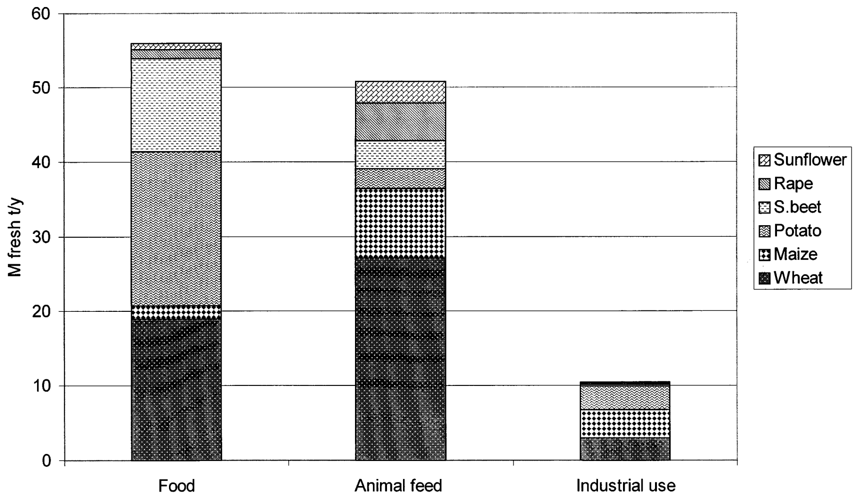

Fig. 2. Current uses of selected crops in Middle Europe (in M fresh tonne per year).

sam, 1998). Thus, both miscanthus and sweet sorghum have a great potential of improvement, especially within the framework of emerging technologies, e.g. genetic engineering.

As far as conventional crops are concerned, most of them have a long history of cultivation in Europe. In recent decades, plant breeding has permitted good progress in enhancing crop yields and improving the genetic make up of these crops to increase nutrient utilisation efficiency and improve adaptability under wider environmental conditions (El Bassam, 1998). Thus, nowadays, the total biomass of these crops that can be utilised (main product + residues) for food and energy purposes is of the same order of magnitude as that of agro-forestry crops.

In the near future, crop productivity is expected to grow; however, at slower rates than those of previous decades. According to EFMA (1997), (European Fertiliser Manufacturer's Association), better farming methods and the availability of improved crops varieties will be the main factors for this improvement.

The extrapolation of crop yields was based on data from FAO for the years 1970–1990. More precisely, the historical data were used to calculate the increase rate during these years. Based primarily on these values, and taking into account some other trends of the agricultural sector (e.g. reduction in fertiliser and pesticides application rates), the values in Table 3 were calculated. Because of the very low increase rates of some crops during the period 1970–1990, their yields are stabilised after 2020.

3.3. Biomass production costs

Unfavourable economics constitutes the most common objection raised regarding the use of biomass for energy and materials. Feedstock prices and costs of converting biomass to power,

Table 3
Average current and projected yields of selected crops (dry tonnes per hectare) (FAO)[a]

	1990	2000	2020	2050
Wheat (M)	5.9	6.7	7.4	7.7
Maize (M)	7.1	7.4	8.2	8.6
Rape (M)	2.7	2.8	3.5	3.5
Sunflower (M)	2.3	2.5	2.8	2.8
Potato (M)	6.4	7.1	7.9	7.9
Sugarbeet (M)	8.4	8.8	9.2	9.2
Sugar beet (S)	7.3	7.5	7.9	7.9
Miscanthus (S)	–	23.6	27.4	29.5
Miscanthus (M)	–	20.3	23.6	25.4
Poplar (M–S)	10	11.1	12.2	12.2
Sweet sorghum (S)	–	35	40.6	43.8
Willow (M)	10	11.1	12.2	12.2
Eucalyptus (S)	16	17.7	19.5	19.5

[a] M, Middle Europe; S, South Europe; M–S, Middle and South Europe average.

Table 4
Estimated production costs of selected crops in 1995 (ECU per dry time)[a]

Crop	Cost
Wheat (M)	110–211
Maize (M)	135–211
Rape (M)	305–488
Sunflower (M)	176–245
Potato (M)	390–595
Sugarbeet (M)	203–316
Sugar beet (S)	131–238
Willow (M)	69.4–75.4
Poplar (M)	101.1–143.4
Eucalyptus (S)	63.0–74.8
Sorghum (S)	40.0–63.0
Miscanthus (M)	76.0–83.3

[a] Data are from Panoutsou and Dalianis, 1996; Walsh and McCarthy, 1996; European Commission, 1997b; Venendaal et al., 1997. M, Middle Europe; S, South Europe.

fuel or chemicals must be competitive with those of conventional fossil sources in order to be attractive to utilities and chemical companies. To ensure adequate supplies of biomass feedstocks, growing these crops must also be attractive to farmers, since the latter will be asked to convert agricultural land from the production of food crops to that of non-food crops.

Production cost consist of:
- variable cash expenses (e.g. seeds, chemicals, fertiliser, fuel, repairs, hired labour);
- fixed costs (e.g. overhead, taxes, interest payments); and
- the costs of owned resources (e.g. producer's own labour, equipment depreciation, land rent, etc).

All these costs show great variation between countries and, even more, between production sites. Among the main factors determining production cost (e.g. price and quantity of input chemicals, etc.), one of critical importance is the yield achieved at each location. Thus, any estimation of production cost includes a great margin of uncertainty.

In order to reduce this uncertainty, producer prices can be used as an upper limit for production costs. These prices include both production costs and producer profit. Such values were obtained from the European Union's DG VI (European Commission, 1997b) and are presented in Table 4.

A lower limit of production costs can be calculated by multiplying producer prices by the share of inputs in the total costs. The share of inputs in production represents the proportion of all the inputs required for growing a crop (i.e. fertilisers, pesticides, diesel, labour, etc).

The data on production costs for industrial and agro-forestry crops found in the literature are scarce and not well documented. Thus, in order to reduce the uncertainty and keep a minimum of consistency with the cost of conventional crops, only values for crop prices at the farm gate are presented. According to Venendaal et al. (1997), the production costs of these crops can be substantially reduced if higher yields are achieved.

4. Discussion and conclusions

European agriculture should be able to provide consumers and industry with adequate quantities of healthy and high-quality food products, and protect the environment (Fischler, 1998). Environmental protection should not only include local or regional aspects, like soil erosion and groundwater contamination from fertilisers leaching, but even global aspects like greenhouse effect mitigation. Agriculture can play an active role in this field through the introduction of higher quantities of biomass as a substitute for fossil energy carriers and for materials.

Within this framework, a number of conventional and industrial crops have been evaluated in terms of current production and use, yield and costs. Through this analysis, several interesting aspects were highlighted.

Among the crops discussed, cereals are the most widely cultivated crops; wheat and maize production in the Middle European countries amount to 61.4 and 15.8 M dry tonnes per year, respectively. Since they serve as sources for food and feed, they are highly developed and the knowledge for their production is widespread among farmers. Therefore, the production of these crops for non-food purposes can be easily implemented in agriculture, and high as well as stable yields can be expected (Venendaal et al. 1997).

Oil crops (rape and sunflower) are, like cereals, well-known crops to farmers as they have been developed for food production. Thus, only slight yield increases are expected in the case where they are used for energy and materials. The production of these crops for energy (i.e. bio-diesel) in many European countries indicates that farmers do have interest in producing bioenergy feedstocks as long as there is a well-established market and a well-known technology (Jorgensen and Venendaal, 1997).

The production of most of the industrial and agro-forestry crops for energy is still at the research and development stage. The discussed crops are suitable for cultivation under various climatic conditions throughout Europe. Crops like sweet sorghum and eucalyptus are only grown in South European countries, whereas poplar and miscanthus can grow both in Middle and South Europe. The high yields that have been reported (20–35 dry tonnes per hectare) are from small research plots. However, it is believed that such high yields can be also achieved under typical farming conditions in the near future.

As far as most of these crops are at research stage, there is a significant room for reduction of the production costs. Recent tests with miscanthus in several European countries have shown that production costs can be reduced from 4000–5000 ECU per hectare to less than 1000 ECU per hectare (Huisman and Kortleve, 1994; Jorgensen, 1994; Pari, 1996).

Undoubtedly, production cost is the main factor that will determine the introduction of the industrial crops in the agricultural sector of Western Europe. However, the extent of their introduction will also depend on the amount of land that will become available within the following years. This land may come after currently set aside land or might originate from less-productive areas presently cultivated with conventional crops. According to scenario studies for Western Europe, the available land for industrial crops will be about 20–25 Mha (16% for North Europe, 56% for Middle Europe and 28% for South Europe) (Lako and Gielen, 1997).

This land can support the production of about 90 Mtoe of energy (heat and electricity as well as transportation fuels) (Table 5). This figure fully agrees with the amount of biomass required to fulfil the goal of 12% share of renewables in the EU's total energy consumption in 2010, as set in the White Paper for energy (European Commission, 1997a).

In conclusion, both conventional and industrial crops offer a good opportunity for energy production but as far as the range of end-uses is enormous, an optimal allocation of limited agricultural land sources is required.

Table 5
Estimated amount of bio-energy production in Western Europe available land (2020)

	North	Middle	South	Western Europe
Crop cultivated (Mha)				
Willow	4	4		8
Cereals		4		4
Rape		4		4
Sorghum			3	3
Eucalyptus			3	3
Total	4	12	6	22
Product (Mtoe)				
Ethanol	–	6	15	21
Diesel		4		4
Heat and electricity	15	30	20	65
Total	15	40	35	90

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