WOODSUSTAIN

Contributions of wood energy to sustainable development in Belgium

Final Summary

September 2001

Ir. I. Sintzoff & Prof. J. Martin
Groupe Energie Biomasse
Université catholique de Louvain

Ir. J.F. Menu & M. Temmerman
Station de Génie Rural
Centre de Recherches Agronomiques de Gembloux

J. Thiry & Prof. D. Tyteca
Centre Entreprise Environnement
Université catholique de Louvain

W. de Raedt, Dr. E. Casella & Prof. R. Ceulemans
Research group of Plant and Vegetation Ecology
Universiteit Instelling Antwerpen

Ir. X. Dubuisson, Ir. J.M. Jossart & Prof. Ledent
Laboratoire d'Ecologie des Grandes Cultures
Université catholique de Louvain

This final summary has been written in September 2001 by Ivan Sintzoff (Groupe Energie Biomasse - http://www.term.ucl.ac.be/geb).

Acknowledgement

WOODSUSTAIN has been fully funded by OSTC (http://www.belspo.be), the Federal Office for Scientifc, Technical and Cultural Affairs. WOODSUSTAIN is a study undertaken in the period 1997-2000 in the framework of the national program called "Plan d'Appui Scientifique à une Politique de Développement Durable".

Glossary & abbreviations

$kgCO_2$	1 kilogram of fossil carbon dioxide equivalent
odt	1 oven dried ton = 1 ton of dry wood
ha	1 hectare = a surface of 10,000 m^2
odt/a	1 ton of dry wood per annum
odt/ha	1 ton of dry wood per hectare
man-year	1 man working during 1 year.
ton	1 ton of matter
MW_{th}	10^6 Watt of thermal power produced or consumed.
MW_{el}	10^6 Watt of electrical power produced or consumed.
MWh	quantity of energy produced (or consumed) by a machine developing 10^6 watt during one hour, i.e. 3,6 10^9 Joule
MWh_{heat}	quantity of heat produced (or consumed) by a machine developing 10^6 watt during one hour, i.e. 3,6 10^9 Joule.
MWh_{elec}	quantity of electricity produced (or consumed) by a machine developing 10^6 watt during one hour, i.e. 3,6 10^9 Joule.
SRC	Short Rotation Coppice

1. Summary

WOODSUSTAIN is a partnership of 5 research centres located in Belgium. Initiated and co-ordinated by GEB, the Groupe Energie Biomasse of the Université catholique de Louvain, WOODSUSTAIN aims to precise the wood energy potential available in Belgium and to assess the impacts of wood energy development on greenhouse gases emissions, on job creation and on the local economy.

In this project, GEB has calculated the life cycle analysis of number of wood energy systems in order to estimated the fossil energy consumption, the CO_2 emissions and the CO_2 reductions related to wood energy use. CRA, the Centre de Recherches Agronomiques working on wood resources and wood fuels handling, has estimated the quantities of wood resources available in the Belgian forests and the industry. ECOP, the Laboratoire des Grandes Cultures of the Université catholique de Louvain working on energy cultivation, has estimated the potential of short rotation coppice cultivation in Belgium. CEE, the Centre Entreprise Environnement of the Université catholique de Louvain, has estimated the job creation in wood energy systems and analysed the local economy of wood energy projects. PLECO, the Research group of Plant and Vegetation Ecology of the University of Antwerpen, has improved the mathematical modelling of poplar coppice growth.

The estimations of wood energy available are about 10,000 TJ/a in Belgian forests and 19,000 TJ/a in the wood industry (including construction and demolition industry). All this wood could not be completely consumed for energy purpose because other uses are already developed, mainly in the paper and panel industry where 35% of the industrial wood residues are recovered. In addition to this resource available from now, WOODSUSTAIN has estimated the potential for short rotation coppice cultivation in the next 10 years at 12,000 TJ/a. A reasonable projection is an increase in the wood energy consumption of 10% each year leading to 30,000 TJ/a in 2010 and 50,000 TJ/a in 2015. This wood energy consumption will avoid the burning of fossil energy and then reduce fossil CO_2 emissions in 2010 by 1.5 to 3.4 millions tons of CO_2 (i.e. 1.2% to 2.7% of the total 1990 equivalent CO_2 emissions in Belgium). The manpower needed to harvest and to prepare this local fuel will be between 2,000 and 3,000 mans fully occupied. The total investment required for having sufficient modern power plants and wood heating equipments has been evaluated between 250 and 2,500 millions euros.

2. Main results

2.1. The wood energy resources

(1) Forest wood energy resources

CRA estimates that 224,000 odt/a of wood residues are annually abandoned in broadleaf forests and 321,000 odt/a of wood residues in needleleaf forests. Adding Brussels forest, that is about 546,000 odt/a of wood residues annually left in the Belgian forests. Based on an estimation of 290,000 ha of broadleaf forests and of 252,000 ha of needleleaf forests, the average wood forest residue is about 0.7 odt/ha/a in broadleaf forests and 1,3 odt/ha/a in needleleaf forests.

After integration and confrontation of these data with other studies, GEB notes that the CRA results must be carefully considered because this estimation is about 24% of the natural increment of matter in Belgian forests. This figure seems relatively high taking into account that the mean harvest ratio in Belgium is estimated at 65% (2,2 millions m^3/a harvested of the 3,4 millions m^3 biological growth [CdB, 1985]). If the 24% available as wood residues would be harvested for energy, the total harvest of woody material in our forests will be 89% of the biological growth. International experts recommend to limit the total removal of wood to be less than 80% of the natural growth. In this case, wood residues in forests available for energy purpose are limited to 15% of the biological growth, that is to say about 342,000 odt/a. CRA and CEE have evaluated the cost of harvesting these forest residues. Depending on the type of residue and on the choice of the harvesting practice, forest wood chips will cost between 40 EUR/odt and 80 EUR/odt.

(2) Industrial wood energy resources

The data recovered from the CRA surveys precise the production of wood by-products (bark, off-cuts, shavings, sawdust, etc.) in the Belgian industry. The total production has been estimated at 857,000 odt/a. This wood is not fully available for energy because 35% is already consumed in the paper & pulp industry.CRA has estimated the price value of these by-products by asking to the companies what are the present prices they receive for their woody by-products : bark is valued between -40 and +50 EUR/odt, wood chips between 17 and 72 EUR/odt, sawdust between 0 and 50 EUR/odt, demolition wood between -75 and -25 EUR/odt. These prices vary mainly with the quality of the by-product, with the distance from an important consumer and with the volume of the production.

GEB notes that some uncertainty remains after the CRA surveys. In order to confirm these data, GEB has compared them with the French ratios obtained from a similar survey to 4,700 companies [CTBA, 1992]. Applying these ratios, a total of 808,000 odt/a wood residues could be available in sawmills, joineries and furniture manufactures while CRA obtains 685,000 odt/a. The difference is more important between CRA estimation and CTBA ratios for the furniture sector. The low representativity of the CRA sample (16 companies of 163) could be a reason. CRA has not taken into account the wood residues coming from used package as broken pallets. About 200,000 odt/a of pallets are not reused in Belgium [iTER, 1998]. About the estimation of wood costs, the uncertainties remain important. Wood costs depend on a lot of parameters : wood quality, distance of the main wood user, etc. Further, uncertainties on wood costs are also coming from the uncertainties on wood quality. The producers of wood by-products do not know very well their wood quality (moisture and volumic mass). It is still difficult to have a good estimation of the wood cost per energy unit (EUR/GJ), even when knowing the wood cost per volume or per ton (EUR/m^3 or EUR/ton).

(3) Agricultural wood production

ECOP has proposed three scenarios for developing Short Rotation Coppice (SRC) as the main solution for wood production in the agriculture. The medium scenario suppose that 5% of the Total Utilised Agricultural Area will be converted to SRC cultivation. In this case, 66,000 ha will be planted. ECOP estimates at 717,000 odt/a the wood fuel production on agricultural land. These scenarios are in accordance with the European Commission scenario (White Paper, 1997) which propose a 6,3 millions hectares of cellulosic plantation for energy purpose in 2010. This is about 4-5% of the European TUAA. The average productivity estimated by ECOP at 10.8 odt/ha/a is not far from the European estimation of 10 odt/ha/a. We could then accept the medium scenario as a good estimation of the future development of agricultural cellulosic cultivation. If SRC was replaced by an other cellulosic plant (as miscanthus), the energy potential will not be so different.

(4) Estimation of the total wood energy potential and of the costs

Table 2	Estim. quantity - TJ/an	Estim. deviation - TJ/an	Estim. mean cost - EUR/GJ	Min cost - EUR/GJ	Max cost - EUR/GJ
All forest residues without stumps	10,158	0	3.5	1.6	8.8
Scenario of SRC production	12,902	6,300	4.0	2.7	11.0
Sawmills by-products	7,506	468	0.3	-2.1	7.6
Joineries by-products	3,537	315	0.1	-1.2	1.6
Furniture manufactures residues	2,474	986	0.1	0.0	2.7
Residues from packaging industries	557	0	-0.1	-4.0	2.1
Construction & demolition wood	2,552	324	-0.6	-4.0	0.0
Wood residues from other industries	2,412	2,088	-0.6	-4.0	0.0
Total wood energy	42,098	10,481	2.1	-4.0	11.0

2.2. The wood energy technologies

(1) Production of wood fuels

Different systems to produce wood fuels have been identified and assessed. The steps to produce wood fuels are : cultivate, harvest, chipping, transport, storage, drying, crushing, pelletizing/densifying. Depending on the wood resources and on the type of wood energy use, one or more of these operations will be applied. For example, wood fuels production by SRC cultivation could be decomposed in 4 steps (cultivate, harvest/chipping, transport and storage/drying) while producing wood pellets from sawdust needs 4 other steps (transport, storage/drying, pelletizing/densifying, transport).

With the help of ECOP and CRA, GEB and CEE have modelled the cultivation of SRC, the harvest of forest residues, the transport of wood fuels, the storage & the drying of wood fuels and the densification of wood sawdust. The production of wood fuels from SRC appears expensive relatively to the production cost of wood waste or to the market cost of fossil energy in the nineties. The lower medium cost for SRC wood chips is about 125 EUR/odt (about 50% higher than fuel-oil market price). SRC harvest and chipping is labour intensive, about 2.2 hours/odt. Energy consumption for SRC cultivation is mainly caused by fertilisers consumption and fuel for maintenance and harvesting. This energy consumption emits about 100 kgCO_2/odt, that is to say 5.5 kgCO_2 per GJ of primary energy.

The harvest of forest residues has been modelled with 6 scenario's depending of the level of mechanisation. Low mechanised harvest is well suited for broad-leaved forests while high mechanised harvest is adapted after a complete cut-off of needle-leaved forest. Production of wood chips from forest residues costs 40-60 EUR/odt. Depending on the harvest type, manpower use is between 0.4-2.3 hours/odt. Fossil energy consumption is limited to fuel consumption for machines operation, between 0.3 and 0.7 GJ/odt, emitting 22-50 kgCO_2/odt (1-3 kgCO_2/GJ).

For industrial residues, fixed chipping has been analysed. Depending on the size of the chipper and on the annual production (odt/a), CEE has obtained a classical formula to calculate the chipping cost in EUR/odt (chipping_cost = a . $(\text{annual\_production})^{-b}$ with a = 7090 EUR/odt and b = 0.7026). This is about 50 EUR/odt for annual production lower than 2,000 odt/a, and about 10 EUR/odt for production bigger than 10,000 odt/a. Labour need is between 0.1 and 1.4 hour/odt. Energy cost of chipping is 0.3-0.8 GJ/odt (following the same formula with a = 13,726 MJ/odt et b = 0.4324), emitting 7-30 kgCO_2/odt chipped.

Wood chips must be transported from the production site to the utilisation site. Chips are transported in trailer or container. GEB and CEE have analysed 3 types of road transport : agriculture/forestry tractor and trailer, small truck (30 m^3) and large truck (90 m^3). Transport are estimated around 4.2 EUR/odt for short distance (20 km), 8 EUR/odt for regional transportation (75km) and 32 EUR/odt for international transport (300 km). These value are highly related to the distance (km) and the dry mass volume of the wood fuel transported (odt/m3). Manpower use is respectively 0.2 ± 0.1 (25 km), and 0.6 ± 0.4 (75 km) and 0.8 ± 0.3 (300 km) hour/odt. Energy consumption is respectively 0.17 ± 0.01, 0.18 ± 0.11 and 0.74 ± 0.44 GJ/odt, emitting 10 ± 1, 11 ± 7 and 46 ± 28 kgCO_2/odt.

Storage of wood chips could be done without or with ventilation and drying. Natural drying cost nothing except the area and avoid energy consumption but could led to wood matter losses resulting of the fermentation. After half a year, about 10-15% of wood is fermented and lost. When vented or dried, wood storage is relatively energy intensive 1.8 ± 0.2 and 2.7 ± 0.1 GJ/odt, and emitted carbon emissions 65 ± 10 and 205 ± 10 kgCO_2/odt.

Densification or Pelletisation are two final steps used to produce a standardised wood fuel. Wood pellets or wood briquettes are interesting is some private use of wood fuel. CEE has collected data on these operations given production costs between 20 and 250 EUR/odt, 5-25 hours/odt, 0.8-4.6 GJ/odt and 11-140 kgCO_2/odt. These figures are very uncertain cause of the type of wood densified and the type of densification.

GEB and CEE have analysed 11 types of wood fuels supply systems. Adding all these steps of wood fuels production, we have calculated the cost, manpower, energy and CO2 emissions in 11 types of wood fuels supply systems (see tables 3 & 4).

Table 3	Production cost EUR/odt	Direct Manpower Hour/odt	Energy consumption GJ/odt	CO_2 emissions $kgCO_2$/odt
Cultivation of SRC and harvest into chips :				
1. Low intensive with manual harvest in stems	153 ± 46	2.9 ± 0.2	1.15 ± 0.1	77 ± 11
2. Medium intensive with mechanical harvest in chips	126 ± 36	0.2 ± 0.2	2.00 ± 0.3	147 ± 32
3. High intensive with mechanical harvest in bales	180 ± 53	2.2 ± 0.0	1.41 ± 0.2	104 ± 17
4. High intensive with mechanical harvest in stems	128 ± 38	2.2 ± 0.2	1.36 ± 0.2	100 ± 17
Harvest and chipping of forest residues :				
1. 1 tractor + 1 small chipper + 2 mans	60 ± 26	2.3 ± 1.0	0.29 ± 0.3	22 ± 3
2. 1 tractor + 1 medium chipper + 1 grab + 1 man	48 ± 21	1.0 ± 0.3	0.44 ± 0.7	32 ± 6
3. 2 tractors + 1 big chipper + 2 man	45 ± 12	0.9 ± 0.2	0.67 ± 0.3	50 ± 20
4. 1 forester machine + 1 big chipper + 1 man	47 ± 19	0.4 ± 0.1	n.a.	n.a.
5. 2 forester machines + 1 big chipper + 2 mans	51 ± 13	0.6 ± 0.2	n.a.	n.a.
6. 1 forester machine + 1 tub grinder + 2 mans	42 ± 18	0.5 ± 0.2	n.a.	n.a.
Fixed chipping of industrial residues :				
1. less than 500 odt/a	90 ± 25	1.4 ± 0.7	0.75 ± 0.2	29 ± 13
2. 1,000-2,000 odt/a	50 ± 20	0.7 ± 0.5	0.6 ± 0.3	20 ± 10
3. 3,000-5,000 odt/a	23 ± 7	0.2 ± 0.1	0.4 ± 0.2	13 ± 6
4. More than 10,000 odt/a	10 ± 1	0.1 ± 0.0	0.3 ± 0.1	7 ± 2
Transport of wood chips :				
local transport by tractor & trailer (20 km)	4.2 ± 0.3	0.2 ± 0.1	0.17 ± 0.01	10 ± 1
regional transport by truck (75 km)	8 ± 4	0.6 ± 0.4	0.18 ± 0.11	11 ± 7
international transport by truck (300 km)	32 ± 17	0.8 ± 0.3	0.74 ± 0.44	46 ± 28
Storage of wood chips (6 months) :				
natural storage under shelter	0.1 ± 0.1	0	0	0
vented storage in silo	6.5 ± 2.5	0	1.8 ± 0.2	65 ± 10
dried and vented storage in silo	30 ± 7	0	2.7 ± 0.1	205 ± 10

Table 4		Production cost EUR/odt	Direct Manpower Hour/odt	Energy consumption GJ/odt	CO_2 emissions $kgCO_2$/odt
F1	Broadleaved forest residues harvested after 100 days with a small mobile chipper + local transport to a local user + wood chips storage (max. 180 days).	70 ± 26	2.6 ± 1.0	0.38 ± 0.04	27 ± 3
F2	Broadleaved forest residues harvested after 100 days with a medium mobile chipper + local transport to a local user + wood chips storage (max. 180 days).	55 ± 11	1.1 ± 0.4	0.57 ± 0.08	40 ± 6
F3	Broadleaved forest residues harvested after 100 days with a medium mobile chipper + regional transport to a regional user + wood chips storage (max. 180 days).	56 ± 13	1.6 ± 0.8	0.54 ± 0.13	38 ± 9
F4	Needleleaved forest harvested just after felling with a big forester machine + regional transport + vented storage during 30 days.	72 ± 17	2.2 ± 1.6	1.84 ± 0.53	185 ± 44
F5	Needleleaved forest harvested just after felling with a big forester machine + regional transport + drying storage down to 15% (max. 180 days).	73 ± 17	2.2 ± 1.6	2.25 ± 0.86	162 ± 63
C1	Low intensive SRC cultivation harvested in stems + storage of wood stems on the fieldside (max. 180 days) + chipping of stems + local transport	159 ± 43	3.1 ± 0.2	1.06 ± 0.15	77 ± 11
C2	Medium intensive SRC cultivation harvested in chips + local transport + sheltered storage (max. 180 days).	148 ± 38	1.0 ± 0.8	1.84 ± 0.45	133 ± 32
C3	High intensive SRC cult. + harvest in bales + local transport + chipping + sheltered stor. (max. 180 days).	194 ± 54	3.8 ± 1.5	1.55 ± 0.36	111 ± 25
C4	High intensive SRC cultivation + harvest in chips + local transport + sheltered storage (max. 180 days).	143 ± 41	3.8 ± 1.5	1.50 ± 0.36	107 ± 25

W1	Industrial waste chipped in joineries, chips storage and local use.	7 ± 0.2	0	0.21 ± 0.07	15 ± 5
W2	Industrial waste chipped in joineries, regional transport, final crushing and densification in pellets or briquettes.	142 ± 20	6.2 ± 0.9	2.06 ± 0.16	123 ± 10

(2) Production of energy from wood fuels

GEB has classified wood energy technologies by power range and by type of usage : domestic heating, collective heating and/or power production and centralised power production.

For domestic heating (<100 kW_{th}), 4 different technologies are already available : logs stoves, pellets stoves, logs boilers, chips boilers. In addition, 2 new technologies could become available by 2010 : domestic Stirling engines and micro-gasification gensets. Wood stoves are the main wood energy technology installed in Belgian households. Energy efficiencies (25%-60%) and atmospheric emissions (200-2000 mg_{CO}/MJ_{comb}, 150-900 $mg_{particules}/MJ_{comb}$) have been well improved from 1970. Investment costs in modern wood stoves are very dependant of the stove type and the design, between 100-300 EUR/kW_{th} (classical stoves), 400-600 EUR/kW_{th} (ceramic stoves) [Karlsvik et Sonju, 1991, Senf, 1996, Strehler, 1998 and FEEDS, 1998]. Wood boilers are more and more installed in northern and eastern European countries (15,000 new wood boilers installed in 1996 in Austria, Lasselsberger et al. 1998). Important improve has been realised in boiler efficiency (70%-90%) and atmospheric emissions (50-1,000 mg_{CO}/MJ_{comb}, 50-350 mg_{NOx}/MJ_{comb} and 20-100 $mg_{particules}/MJ_{comb}$). Investments depends on boiler type and power range : 200-400 EUR/kW_{th} for a logs boiler with its hot water tank for heat storage (20-50 kW_{th}), 300-700 EUR/kW_{th} for an automatic wood chips boiler (20-50 kW_{th}). Domestic power generation is at the early stage of development. GEB thinks that domestic cogeneration technologies will be more and more available in the future. 2 different technologies have been analysed : (1) combination of a wood boiler and a Stirling engine and (2) combination of a wood gasifier and a gas genset. These systems are not yet commercial but the technological demonstration is almost done. Global efficiencies will be as high as 70%-90% with 10%-25% converted in electrical power and 45%-80% in heat. The power range is 5-50 kW_e and 10-200 kW_{th}.

For collective heating (<10 MW_{th}), different technologies are available : clean wood boilers, contaminated wood boilers, power steam cycles and gasification gensets. Collective wood boilers could be design for clean wood or contaminated wood. Clean wood boilers are 3 to 5 times cheaper than contaminated wood boilers due to avoiding the investment in a flue gas cleaning system. Investment cost is very sensitive to the boiler size (200-600 EUR/kW_{th} for boiler smaller than 1 MW_{th}, 150-200 EUR/kW_{th} for boiler bigger than 2 MW_{th}, blue area and 400-1,000 EUR/kWth for boilers in the range of 2-5 MW_{th} and 300-650 when bigger than 5 MW_{th}). Thermal efficiencies are between 70% and 105% (for flue gas condensing boilers) with a mean value around 85%. Some wood boilers are integrated in a steam cycle designed in a cogeneration mode. This is rarely done with a boiler size smaller than 10 MW_{th}. Wood gasification gensets are now commercially available on the European market. This concept combines a wood fixed bed gasifier and an internal combustion engine coupled with an alternator. Investment costs are relatively high (2,500-5,000 EUR/kW_e). Total efficiency could reach 70-90% if heat is well recovered : electrical efficiencies are 18-27% and thermal efficiencies 40%-70%. Atmospheric emissions are still high for carbon monoxide (50-250 mg_{CO}/MJ_{comb}, 10 mg_{NOx}/MJ_{comb}).

For centralised power production (> 10 MW_e), technologies are : power steam cycles, biomass integrated combined cycles and co-firing of wood and coal. Steam cycles between 10 MWe and 50 MWe obtain an electrical efficiency between 24%-40% with an important scale effect. For power range bigger than 10 MW_e, investment costs are between 1,500-2,700 EUR/kW_e. Centralised wood gas combined cycles power plants are still in the technical demonstration phase. Electrical efficiencies will reach 35%-40% for 25-30 MW_e. Investments costs are estimated between 1,000 and 2,700 EUR/kW_e for power range bigger than 10 MW_e. The cheapest solution for centralised power production remains the repowering of existing coal power plants in wood and coal co-firing power plants. This has already be done in North America and in Europe in dozen of power plants. For a limited investment (between 100-500 EUR/kW_e), electricity producer could convert an existing coal power plant in a partially wood power plant.

2.3. Contributions of wood energy to sustainable development

(1) Wood energy reduces greenhouse effect

Even after taking into account the fossil fuel consumed for producing wood fuels, GEB concludes that wood energy technologies reduce very much greenhouse gas emissions.

1. Producing wood energy emits between 10 and 230 $kgCO_2/odt$, that is about 0.5-12.8 $kgCO_2/GJ_{comb}$ while the production of fossil fuels emits between 4.4-18.7 $kgCO_2/GJ_{comb}$ for oil, 9-22.5 $kgCO_2/GJ_{comb}$ for natural gas and 1.0-29.8 $kgCO_2/GJ_{comb}$ for coal. We conclude that for the production cycle of fuel, wood energy has a slight greenhouse impact. When taking into account the direct emissions due to the combustion of the fuels, the figures are much more interesting for wood : 0 $kgCO_2/GJ_{comb}$ for wood fuels, 74 kgCO2/ GJ_{comb} for fuel, 56 $kgCO_2/GJ_{comb}$ for natural gas and 94 $kgCO_2/GJ_{comb}$ for coal fuels. When burning wood fuels, the CO_2 released in the atmosphere is exactly the same quantity of CO_2 that has been trapped by the tree during the photosynthesis. Wood fuels are then considered as carbon neutral fuels. In the total life cycle of the fuels, wood emits 10 to 17 less times CO_2 than fossil fuels (see Figure 10).

2. GEB has assessed the reduction of greenhouse gas emissions that could be done in Belgium by replacing fossil fuels technologies by wood fuels technologies. Depending on the hypothesis chosen (cfr. above), the results vary between 750 and 1,700 kg CO_2 avoided by ton of wood consumed. Taking into account that the wood energy resources have been estimated to about 2 millions of tons per year in Belgium (340,000 in forests, 970,000 in the industry and 710,000 in the agriculture), GEB estimates that 1.5 to 3.4 millions tons of CO_2 could be avoided by using wood energy in Belgium (i.e. 1.2% to 2.7% of the total 1990 equivalent CO_2 emissions in Belgium[1]). For each project, the avoidance of CO_2 emissions will depend on the efficiency of the technology, the consumption of fossil energy for wood fuel production and the effective recovery of the heat. For example, Figure 11 compares the reduction of CO_2 emission by consuming 1 ton of wood in different wood energy technologies. The important uncertainty for technologies producing electricity results of the different choices possible for the reference case (cfr. above).

GEB's conclusions are that wood energy systems are drastically reducing fossil CO_2 emissions. In order to profit at the best of the wood resources available in Belgium, high efficiency heating (i.e. collective wood heating) or cogenerating of heat and power (i.e. wood gas gensets or steam cycles) must be installed.

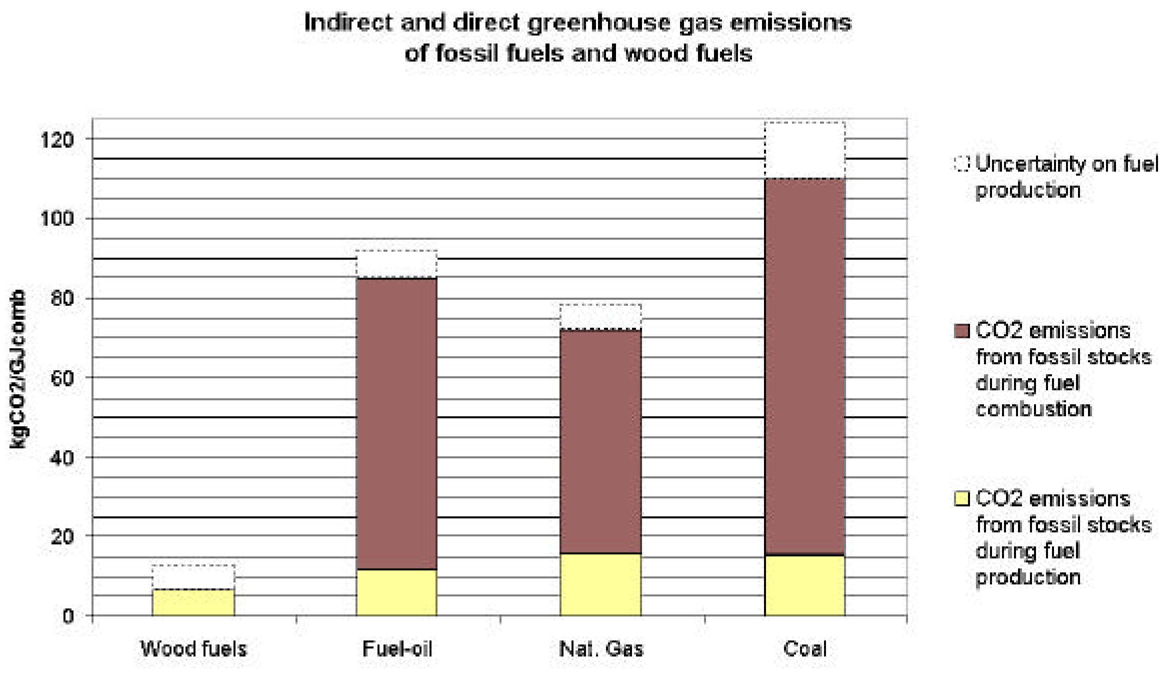

Figure 10 - Emissions of greenhouse gases of main fuels (GEB).

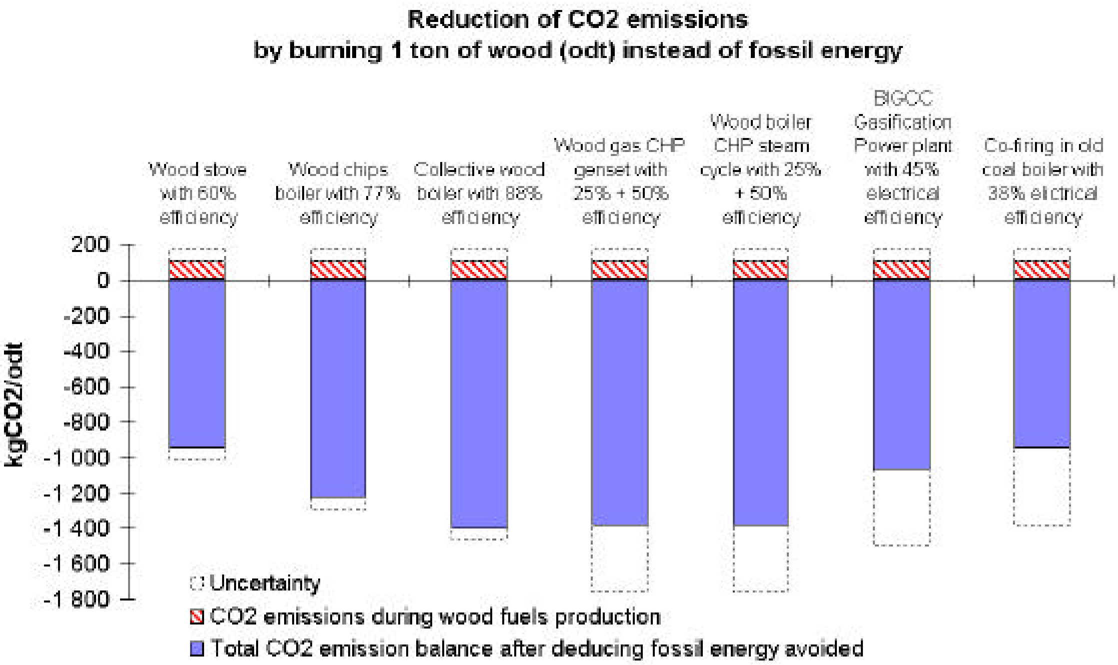

Figure 11 - Reduction of greenhouse gases emissions
by replacing fossil fuels with wood fuels (GEB).

(2) Jobs creation in the wood energy production

CEE has estimated the manpower needed to produce 1,000 TJ of wood energy at 24-350 man-year. That must be compared with the 8 man-year needed for coal production [B. Hektor, 1999]. Applying the CEE estimations to the Belgian wood resources, GEB drawn the curve of job creation in the production of wood fuels. It appears that new jobs will only become important when the demand of wood energy will be big enough to harvest forest residues and SRC. The recuperation of wood waste coming from the industry does not create a lot of jobs in the fuel chain. In Belgium, the job creation in the wood fuel production is estimated to 2,200-3,000 jobs.

(3) Profitability of the wood energy production

CEE has analysed the profitability of wood energy technologies. The comparison between 14 technologies has been done. For the domestic heating, it appears that wood energy becomes profitable if the price of wood fuels is lower than 90-125 EUR/odt. For collective heating or cogeneration of heat and power at small-scale (<10 MW_{th}), clean wood fuel cost must be lower than 160-140 EUR/odt. Cost of contaminated wood fuels must be lower than 15 EUR/odt. For power production, even with wood cost at 125-260 EUR/odt, power plants are profitable.

GEB considers that these results must be considered very carefully because of the choice of assumptions. CEE supposes that the electricity and the heat produced will be sold always at the same prices. These prices have been chosen by CEE as high as 148 EUR/MWh_{el} and 43 EUR/MWh_{th}. A second important factor is the annual operation time of each technology. CEE has chosen 4,000 hours per year for all technology. The third assumption that we must take into account is the rate of discount chosen. CEE has always applied the same rate equals to 6,75%. Finally, the fourth assumption is the life duration of each technology.

2.5. Modelling of the poplar coppice growing

PLECO has developed and utilised two models : (1) a tri-dimensional model of the coppice architecture (FRACPO) and (2) a model of the light radiation interception (RATP). There are 20 input parameters for the FRACPO model and 12 for the RATP model. In the FRACPO model, 12 parameters have been measured, the rest has been found in the literature. In the RATP model, 10 parameters have been measured by PLECO.

Experimental observations of the structure and its evolution in the time have been done on 3 clones (Wolterson, Fritzi Pauley et Hoogvorst) in 1999. These results allow to (1) test, adapt and validate the FRACPO model and (2) to simulate the carbon accumulation for the experimental surfaces, in one or more growth season with the RATP model. The modelled results are compared and validated with the experimental results measured on the accumulated biomass quantity after three years of growth in the stems and branches of a poplar coppice.

2.6. Advising the regional and federal decison-makers

From 1999, GEB has contacted and advised decision-makers in Belgium in order to prepare the development of wood energy. Main advice has been done on the production of electricity from renewable resources because of the liberation of the electricity market was the major preoccupation of decision-makers. GEB has deeply analysed the different political systems available for developing the production of renewable electricity despite their higher production cost. Main conclusions are that (1) premiums or quotas must take into account the different production cost of the different renewable sources and systems, (2) premiums or quotas must favour the more efficient technologies, (3) premiums and quotas must take into account the real CO_2 emissions of the renewable technologies (using the ISO 14040 standard). GEB has proposed different solutions in order to implement some of these recommendations in the framework of the new laws and orders to liberalise the electricity markets. Some of these recommendations have been taken into account in Flanders or in Wallonia (minimum and maximum prices for green certificates, fixed objectives on a medium term period).

3. Final evaluation & future prospects

WOODSUSTAIN has reduced uncertainties about renewable energy resources in Belgium. Figures indicate that wood energy could play an important role in reducing the emissions of greenhouse gases in Belgium. An increase in wood energy use at a rate of 10% annually seems reasonably reachable in consideration of the wood resources presently wasted in Belgium and in consideration of the agricultural potential for short rotation coppice. Energy from wood fuels would then represent 30,000 TJ/a primary energy, reducing the carbon dioxide emissions of about 1.2 to 3.4 millions tons equivalent CO_2 per year and employing about 1,500-2,500 more unskilled mans for the production of the wood fuels. The consumption of this local source of energy will reduce national imports of fossil energy of 100-200 millions euros per year. The development of wood energy at this annual rate will require new investments of 25-250 millions euros per year.

However, this objective could not be reached without new political decisions. Depending of the evolution of the fossil energy prices, wood energy could be or not profitable. Investors must be reassured on the future evolution of energy prices. Different measures could be chosen by decision-makers (1) to maintain energy prices at a sufficient high level so that wood energy will be competitive (environmental taxes and detaxation of renewable energy), (2) to force energy suppliers to distribute quotas of renewable energy (green certificates). The production of wood fuels must be assured by helping new cultivation of SRC and forest residues harvest.

In the future, these political instruments must be more precisely studied. In particular, decision-makers have decided to impose quotas of renewable electricity in Belgium via a green certificates system. This system could create important distortion between heat production and electricity production. The international trading of green certificates will also create important risk for renewable energy producers. Other important issues are (1) Who will benefit of the Kyoto credit for the CO_2 reduction in relation with the green certificate trade ?, (2) How to create a green certificate system for heat production and for transportation fuels ?, (3) How to avoid the competition between energy use and material use of wood resources ?, (4) How biomass fuels could be imported from infinite resources (world biomass production is 6 times more than the energy consumption of the humanity) ?