SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY

SPSD II

LIQUID BIOFUELS IN BELGIUM IN A GLOBAL BIO-ENERGY CONTEXT

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PART 1

SUSTAINABLE PRODUCTION AND CONSUMPTION PATTERNS

GENERAL ISSUES

AGRO-FOOD

ENERGY

TRANSPORT

SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY
(SPSD II)

Part 1:
Sustainable production and consumption patterns

FINAL REPORT

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GLOSSARY

BTL	Biomass To Liquid
CHP	Combined Heat and Power
DDGS	Dried Distillers Grains Soluble
DME	Dimethyl ether
EJ	Exa Joule = 10^{18} Joule
ETBE	Ethyl Tertiary Butyl Ether
FT	Fischer-Tropsch
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GJ	Giga Joule = 10^{9} Joule
GJp	Giga Joule primary energy
IC	Internal Combustion
IO	Input-Output
LCA	Life Cycle Analysis / Life Cycle Assessment
LHV	Lower Heating Value
MTBE	Methyl Tertiary Butyl Ether
ORC	Organic Rankine Cycle
PJ	Peta Joule = 10^{15} Joule
PPO	Pure plant oil
RME	Rapeseed Methyl Ester
SPA	System Perturbation Analysis
SRF	Short Rotation Forestry
TOE	Ton of Oil Equivalent = 41.868 GJ

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1 INTRODUCTION

Context

Recent national and international policy initiatives regarding the application of biomass for energy purposes will have a strong impact on the Belgian energy landscape on the short to medium term. The EU directive promoting the use of renewable fuels for transport in particular aims at a minimum proportion of liquid biofuels and other renewable fuels in all Member states. In line with these policy initiatives, several regional and federal policy measures have been implemented. As a consequence, many investors, policy makers and energy companies investigate bio-energy routes and a real take-off is expected in the next few years. Hence, the time is right to gain better insight in this complex matter to allow policy makers to optimize this market tendency i.e. to maximize energy, environmental and socio-economic aspects.

Objectives

The overall objective of the present work is to analyze the behaviour of the most promising biomass routes when applied in Belgium. The report includes:

- A full assessment of short and medium term possibilities on biofuels for the transport sector
- A comparison of the potential of local Belgian biomass resources versus imported biomass, liquid biofuels or intermediate products
- Complete Life Cycle Analysis (LCA) on three selected chains
- Greenhouse Gas (GHG) balances of the other routes (following IPCC methods)
- A System Perturbation Analysis (SPA) which investigates the impact of the application of biomass routes on the Belgian System in terms of energy usage, GHG balance and cost figures

Approach

An assessment is first made of the biomass production potential in Belgium through available literature and data from national statistics. Since local production is limited and imports are probable, the analysis is extended to a full literature overview on the biomass potential in the EU and further worldwide.

A limited number of biofuel routes is next selected. Each biofuel route is a chain of steps, which are grouped into:

- Production
- Transport to conversion site
- Conversion
- Distribution
- End use

A very wide variety of biofuel chains exist, since many possible biomass feedstock's can be applied into different logistical steps, conversion routes and types of end use. A selection of relevant biofuel chains under Belgian circumstances is made, based on resource, import, demand and existing industrial and agricultural infrastructures. The selection includes available short term possibilities (2005-2010) and medium-term perspectives (2020). Routes which are still in an early stage of development are considered as too hazardous to be included. Their potential impact can however be analysed through sensitivity analysis of some key parameters such as increasing surface biomass yields and conversion efficiencies, or bringing specific costs down.

For the environmental sustainability, a full life cycle assessment (LCA) is performed on three selected biofuel chains according the ISO 14040 standard. The other chains are examined according to IPCC (greenhouse gas balance methods). Since the present work aims at comparing more globally a variety of biomass options, another type of analysis is made which is denoted as System Perturbation Analysis (SPA). The SPA computes the impact of a perturbation of the considered system, such as replacing a hectare of set-aside land by a hectare of rapeseed for PPO production, thus reducing the import of fossil fuel, but taking into account all secondary consumptions and by-products which on their turn affect other imports, exports or local productions. As a result, it is possible to determine the best usage of limited resources such as hectares, wood waste, imports or other, in terms of fossil energy savings, GHG emissions and costs, within a given system which in the present case is Belgium. A new software tool has been made available for this rather new type of analysis.

2 BIOMASS POTENTIAL

2.1 Biomass potential in Belgium

Approach

The quantification of the amount of biomass resources available for energy is a hazardous task owing on the one hand to the wide variety and disparity of biomass resources, going from wastes over residues to energy crops, and on the other hand owing to the uncertain social, juridical and economic constraints. Some of these resources have no market and therefore no trade records, such as small forest residues or leaves after harvesting operations. Other residues are traded informally, such as domestic firewood, straw for animal feed or animal bedding, and trade records are unreliable. Besides the problem of getting reliable data, the biomass potential is subject to limiting boundary conditions such as technical limitations, juridical constraints and economical conditions [Nikolaou et al., 2003].

There are therefore several ways to approach the biomass potential. According to the ElGreen project [2001], the following definitions can be given (Figure 2-1) :

- The theoretical potential is defined as the total annual production of all resources given no limits. This potential represents the total quantity of biomass resources in a region and can be considered as the upper bound of bio-energy.
- The technical potential is defined as the total production when technical constraints are considered.
- The socially acceptable potential takes into account the value the society gives to these renewable energies (public acceptance limits the technical potential).
- The realizable potential represents the potential which is achievable through an ambitious promotion program. It is expressed through market growth rates and planning constraints which limit the market penetration at a certain time.
- The mid-term potential is equal to the realizable potential half away the target year (2010).

Figure 2-1 illustrates the disparity of the potentials, taking into account the aspects mentioned above. Factors influencing the different potentials are [Neyens et al., 2004]

- Local climatic conditions
- Space:
  - Availability
  - Competition between uses
- Technology:
  - Conversion yields
  - Availability of the required technology
  - Competition between conversion techniques for the same biomass
  - Usefulness of waste / byproducts

- Agriculture:
  - Crop species and varieties
  - Soil type and productivity
- Ecology and Society:
  - Ecological impact (direct and indirect)
  - Recycling of waste
  - Acceptance (NIMBY)
- Economy:
  - Socio-economic: job opportunity, …
  - Micro-economic: production costs, energy prices
  - Long-term price guarantee
  - International market of energy, raw material, certificates, …
- Politics:
  - Management strategy, incentives, legal framework, …

The difference between the 'business as usual' and the 'achievable potential' scenario's in Figure 2-1 depends solely on the strategy adopted by the policy makers with respect to the last three items.

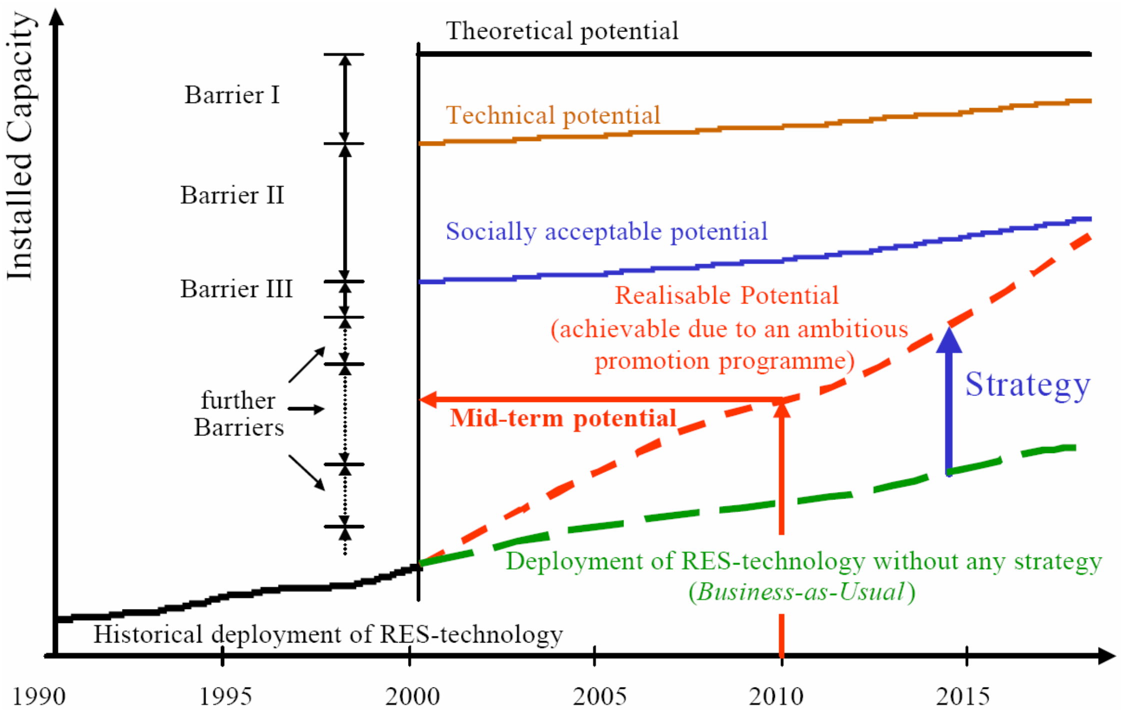

Figure 2-1: Levels of potential [ElGreen, 2001]

Overall theoretical potential

The present potential evaluation is limited to the biomass resources given in Table 2-1, where the candidate resources can compete for transport, heat or power production. The technologies considered in the last column will be discussed in Chapter 3. Table 2-2 shows the available land in the different regions of Belgium in 2004. Roughly speaking a total of some 1400 kha arable land and 700 kha forest area are available. Forest area is found mainly in the Walloon region, arable land is more equally distributed but is still more important in the Walloon region.

Table 2-1: Considered biomass (in Belgium) in the present study:

Sector	Resource		Conversion technology
Agriculture	Agricultural residues	Lignocellulosic (e.g. straw)	Gasification, liquefaction
	Energy crops	Lignocellulosic (e.g. SRC)	Gasification, liquefaction
		Rapeseed (rapeseed oil)	Cold pressing + esterification
		Sugar beet and winter wheat	Fermentation
Forestry	Wood	Lignocellulosic	Gasification, liquefaction
	Forest residues	Lignocellulosic	Gasification, liquefaction
Waste	Waste wood	Lignocellulosic	Gasification, liquefaction
	Waste vegetable oil		Esterification

Table 2-2: Available arable land in [INS, 2004; www.houtinfobois.be] (in ha):

	Belgium	Flemish Region	Walloon Region	Brussels Capital
Useful Agricultural Surface (2004)	1 393 789	633 769	759 772	246
Forest surface (2000)	692 916	146 381	544 800	1 735
TOTAL	2 086 705	780 150	1 304 572	1 981

Sources: INS, 2004 for agricultural data; www.houtinfobois.be for the wood data.

Table 2-3: Overall requirements when using agricultural surface only

	2% goal	5.75% goal	10% goal
10 000 ha/PJ liquid fuel	5.9%	16.5%	28.5%
40 000 ha/PJ liquid fuel	23%	66%	114%

Table 2-4: Energy content of the potential biomass for biofuels production in Belgium (2005)

Sector	Resource		Land area (ha)	Energy content (toe/yr)	Energy content (PJ/yr)
Agriculture [INS, 2004]	Winter wheat	Grain	200 365	336 067	14.07
		Straw		140 949	5.90
	Sugar beet		87 754	299 281	12.53
	Rapeseed	Grain	5 556	7 110	0.30
		Straw		5 583	0.23
	Fallow land		26 025	30 199	1.26
Forestry [Woodsustain, 2001]	Forest residues		-	242 667	10,16
	Wood industry residues		-	454 763	19,04
	SRC scenario		-	-	(12,90) [2)]
Waste [1)]	Oils and fats			56 764	2.38
TOTAL				1 573 383	65.87

1) 62 kg/yr/person produced annually in Belgium [Mittelbach, 2004], of which 10% [Vito, 2001] can be recovered for biodiesel production.

2) Not taken into account because improbable

Based on these numbers, a rough estimate of land use can already be made in Table 2-3, assuming all the biofuel is produced solely from arable land. As will be found in Chapter 6, the surface areas required for replacing gasoline and diesel at tank level range between some 10 000 and 40 000 ha per PJ replaced fuel, where the lower limit is obtained when using short rotation forestry wood and the higher when making rapeseed for biodiesel. Ethanol from wheat and sugar beet are in between. The global usage of liquid fuel for transportation in Belgium is roughly 400 PJ per year, and surface requirements to replace 2%, 5.75% and 10% are given in Table 2-3. From this table it is clear that domestic rapeseed, wheat and eventually sugar beet call for 5 to 10% of the arable land for every 1% replacement at tank level. It must be stressed that replacing 1 GJ of fossil fuel at the car level does not mean saving 1 GJ fossil fuel globally, as is further detailed in Chapters 5 and 6. Pending on the resource and technology used, the surface requirement can therefore be twice the levels given in Table 2-4. Surface requirements can however reduce as yields are continuously improved by application of biotechnology. A doubling of yields is considered as feasible on the medium to long term.

It is clear that other than arable land must be used to achieve reasonable goals. Biofuels from short rotation forestry through newer techniques can significantly reduce the surface requirement whilst residues from the forest land can be added into the potential. The use of wood for liquid fuels is however in competition with other usage such as power, heat, construction material and even biomaterials such as bioplastics. Short Rotation Forestry (SRF) is moreover still in the development phase and will require much effort to become reality.

Finally, an important contribution from wastes and residues adds up to the global potential. Table 2-4 shows the current yields in energy for the considered crops, with addition of energy from residues and wastes. From this table, some 28 PJ of gross biomass energy are produced from the non-lignocellulosic crops, 2.4 PJ from non-lignocellulosic waste and 6.1 PJ from lignocellulosic waste from crops. Some 29 PJ would be available from wood residues from both industry and forests. Waste from industry is however already in use for applications such as recycling for materials, heat recovery and more recently for power and/or CHP production.

Technical biomass potential

Economic factors

Some available techniques are not yet financially attractive for actual energy prices or they need further development. For example, wood harvesting (SRF) and extraction techniques will progressively become more accessible, as the technique spreads; ethanol production from lignocellulose is not expected to be commercially available before 2015.

Technical factors

Whether the demand for sustainable transport fuels can be answered or not, depends on the availability and on the market of the extraction and conversion techniques. There is a rotational restriction on rapeseed, due to the risk of soil borne infections such as club root. It should not be grown more often than one year out of three, and one year out of five is recommended [Easson et al., 2004]. Rapeseed and sugar beet are not easily grown in the same rotation and rapeseed is not adapted to sandy soils. Moreover, some agricultural and forestry waste materials are already valorised through other paths (e.g. green chemistry, animal feed and bedding, compost, wood panels, etc.).

By-products

Energy crops, when processed, produce valuable by-products. If the amount of processed energy crops comes to increase, this would increase the availability of these by-products. This can provide an alternative solution to the demand for locally sourced protein feed: the Belgian livestock is composed of approximately 36 million poultry, 2.74 million cattle, 6.3 million pigs and 0.2 million sheep, goats and horses together [INS, 2004]. A market is thus available for these by-products whereas today, most animal protein feed is provided by imported soybean. The displacement of the existing market is not easily achieved, because properties of soybean are quite different from the residues from wheat and rapeseed, mainly in terms of proteins and taste.

Considering these factors, we estimated that all the wheat, sugar beet and rapeseed on normal arable land could technically be used for biofuel production in 2005, 2010 and 2015. Rapeseed is also grown on fallow land, which is already used for biofuel production and was taken into consideration in the 2005 scenario. Winter wheat and sugar beet will gradually be grown on fallow land as well and were taken in consideration for the 2010 and 2015 scenario's. There is however a technical barrier for straw and wood. The results for the technical biomass potential for Belgium are presented in Table 2-5.

Socially acceptable biomass production potential in Belgium

Economic factors

The area for energy crops will only increase if it is profitable to farmers. Though there is a 45€/ha payment for energy crops outside the fallow land, other costs are related to energy crops which are not covered by this European financial aid. However, on normal arable land, the energy crop payment can be added to the ordinary payment (last CAP reform).
The increasing yields are a positive economic factor, and there is a general tendency to decrease the use of pesticides as they are costly and not always necessary. Many Belgian farmers are now affiliated to warning systems which help them to spray only when necessary [Jossart et al., 2005].

Technical factors

The impact on landscape is largely dependent on location and which system is replaced. Especially for rapeseed, an increase in the crop production will have an impact on the Belgian landscape. The flowering season in particular would be the most noticeable visually. Public perception of this would be hard to gauge, though most people are probably now more generally amenable to the precepts of green energy [Easson et al., 2004]. However, part of the population could consider this increase to be detrimental to wildlife and visual amenity.
Public acceptance also concerns crops such as wheat. Winter wheat is the traditional crop for food and some people do not accept such crops to be used for energy production.

Health concerns are another possible factor for consideration where large areas of rapeseed are likely to be grown, its pollen being cited by many as a causative factor in the upsurge in hay fever incidence, though this is an area of dispute and counterclaim [Easson et al., 2004].
Public awareness affects the biomass potential for Belgium and it will take some time before:

- most farmers include energy crops in their planning, because they most likely will have the tendency to wait and see "what their neighbours do";
- part of the agricultural wastes are effectively valorised for energy production;
- the public accepts the conversion of human food crops to energy crops.

It was therefore decided to take an increasing percentage in time of the technical biomass potential: 30% in 2005, 55% in 2010 and 75% in 2015, assuming that some biomass will never be valorised because it is too expensive to exploit (Table 2-6).

Achievable biomass production potential in Belgium

The production of biofuels from agriculture is definitely limited by the fraction of available land that can be allocated to energy purposes. Table 2-7, based on discussions with different stakeholders, shows what is considered as socially acceptable in Belgium. A very strong promotion policy could probably increase this area distribution. Table 2-8 shows the possible use of fallow land, based on the mean values of the fallow land area in 2000, 2001 and 2002

(26,025 ha), assuming that the fallow land surface remains constant in time and that the straw is collected. The total potential is in the range of 3 PJ in 2015.

Table 2-5: Technical biomass potential for Belgium

technical potential (ktoe/yr)	**Belgium (2005)**	**Belgium (2010)**	**Belgium (2015)**
Winter wheat	336	370	417
Winter wheat straw	-	-	144
Sugar beet	299	289	305
Rapeseed	7	14	25
Rapeseed straw	-	-	15
waste oil	57	57	58
SRC	-	-	236
waste wood	-	-	121
wood industry residues	-	-	227
fallow land	7	35	69
TOTAL (ktoe/yr)	**706**	**765**	**1 617**
TOTAL (PJ/yr)	**29.5**	**32.0**	**67.7**

Table 2-6: Socially acceptable biomass potential for Belgium in 2005, 2010 and 2015

	2005	**2010**	**2015**
Socially acceptable biomass potential (ktoe/yr)	212	421	1034
Socially acceptable biomass potential (PJ/yr)	8.87	17.6	43.4

Table 2-7: Maximum surface allocation for energy crops in 2005, 2010 and 2015 (ha)

	2005	**2010**	**2015**
Rapeseed (ha)	5 500	8 500	10 000
Winter wheat (ha)	-	25 000	60 000
Sugar beet (ha)	-	12 500	30 000
SRC	-	100	150

Table 2-8: Fallow land occupation in 2005, 2010 and 2015 (ha)

	2005	**2010**	**2015**
Rapeseed (ha)	3 000	5 000	10 000
Winter wheat (ha)	-	5 000	8 000
Sugar beet (ha)	-	3 000	6 500

Table 2-9: Achievable biomass potential for Belgium in 2005, 2010 and 2015

	2005	**2010**	**2015**
Achievable biomass potential (ktoe/yr)	70.6	222	782
Achievable biomass potential (PJ/yr)	2.96	9.28	32.7

In conclusion, the total achievable potential estimation is given in Table 2-9, with some 782 ktoe or 32.7 PJ gross biomass production in 2015.

The implementation plan of the EU directive in Belgium

About ten billion liters diesel and gasoline are consumed each year in Belgium, which represents a little less than 8 million toe or some 400 PJ. This implies that 160 000 toe biofuels or 200 million liters biofuels should be added to the existing fossil fuels in order to achieve the 2% objective set by the European directive 2003/30 by the end of 2005. In terms of energy content, the requirements are presented in Table 2-10 (current consumption of the year 2003 and with the assumption of a yearly increase in fuel consumption of 1.7% between 2003 and 2010).

The proportion of diesel to gasoline on the Belgian market is about 70 to 30. We assume that the proportion of the equivalent biofuels produced will be the same. Two assumptions were made to calculate the energy requirements for Belgium in the coming years. The first one assumes a net yearly increase in the fuel consumption of 1.71% (mean value between 1998 and 2003, Mineco, 2004). The second one assumes a yearly increase in diesel consumption of 8% in parallel with a yearly decrease in gasoline consumption of 4.79% (mean values for diesel and gasoline taken separately between 1998 and 2003).

This implies that at the end of 2005, 131 ktoe (assumption 1) or 139 ktoe (assumption 2) of biodiesel should be introduced on the Belgian market as well as 39 ktoe (assumption 1) or 36 ktoe (assumption 2) of bio-ethanol. To reach 5.75% at the end of 2010, these figures are respectively 409 ktoe / 587 ktoe and 121 ktoe / 82 ktoe. We can observe an important difference between the two assumptions. This illustrates the difficulty to make assumptions on the biofuel demand in the future.

However, one parameter is constant: in order to produce these biofuels, land area is required. Adopting the policy goal that by the end of 2005, 2% of the Belgian fossil fuels consumption should originate from renewable resources, this would mean that 170 ktoe (ass. 1) or 175 ktoe (ass. 2) in 2005 and 531 ktoe (ass. 1) or 668 ktoe (ass. 2) in 2010 should be produced in a "green" way. This would mean a drastic displacement of the agricultural crops to energy purposes, as was already shown in Table 2-2. But the energy supply would not only compete with the demand for sustainable raw material but also with food supply and non-food products.

Table 2-10a: Energy requirements for biofuels production in Belgium (toe/yr)
(assumption 1: fuel consumption increase of 1.71%)

	Current consumption (tons) 2004	toe/year	2005	2%	2010	5,75%
Diesel	6 305 000	6 430 293	6 540 553	130 811	7 120 870	409 450
Gasoline	1 932 000	1 905 790	1 938 468	38 769	2 110 461	121 351
TOTAL	8 237 000	8 336 082	8 479 021	169 580	9 231 330	530 801

Source: [FPB, 2005]

Table 2-10b: Energy requirements for biofuels production in Belgium (toe/yr)
(assumption 2: diesel fuel consumption increase of 8%
and gasoline consumption decrease of 4.79%)

	Current consumption (tons) 2004	toe/year	2005	2%	2010	5,75%
Diesel	6 305 000	6 430 293	6 944 716	138 894	10 204 067	586 734
Gasoline	1 932 000	1 905 790	1 814 502	36 290	1 419 614	81 628
TOTAL	8 237 000	8 336 082	8 759 219	175 184	11 623 681	668 362

Source: [FPB, 2005]

Conclusions

The present section evaluated the biomass production potentials for Belgium in the short to medium term (2015) considering successive barriers to the exploitation of the potential. The results of this analysis are found in Tables 2-4 to 2-10b and are graphically illustrated in Figure 2-2.

First, conversion techniques, crop yields and harvesting and recovery methods all affect the price of raw material and thus limit the theoretical biomass production potential for Belgium. Second, the area of land available for energy cropping will largely depend on the extent to which it is competitive with alternative land uses. Even if a resource has an attractive price, some routes can be better economic or social choices. Third, social factors may reduce the biomass potential.

The energy requirements of Belgium to achieve the European targets set by the 2003/30 directive are 170 ktoe (ass. 1) or 175 ktoe (ass. 2) in 2005 and 531 ktoe (ass. 1) or 668 ktoe (ass. 2) in 2010. In 2010, we calculated in the present study that Belgium can only supply some 220 ktoe. Thus, Belgium cannot produce sufficient biomass to reach these targets. Some other biomass sources such as barley or maize may provide additional but still limited biomass resources. Moreover, adequate market and fiscal measures and strategic political incentives such as investment incentives, tax relief, feed-in-tariffs, systems of quota and certificates, obligations etc. may help increase the achievable biomass potential.

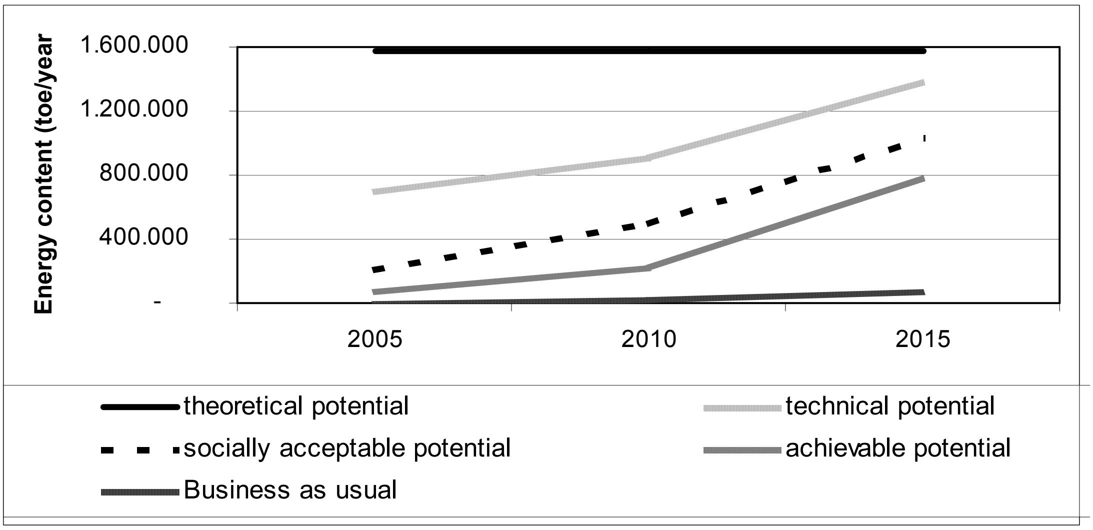

Figure 2-2: Biomass production potential for Belgium

2.2 Biomass potential in the European Union and in the World

Approach

The present section fully relies on available literature where many studies have been undertaken to assess the future biomass energy potential. However, such studies often do not include all sources of biomass and are not always transparent in the procedure for calculating the energy potential. Many studies also tend to neglect or even avoid analysing the competition between various functions for land or for existing residues. Assumptions about (evolutions in) technologies, energy demand, rational use of energy and even population growth also influence the biomass potential. The evolution of total final energy consumption is also required if the potential is calculated as a percentage of the demand.

The reviews from [GAVE, 2003] and [Berndes et al., 2003] give a good overview of existing biomass potential studies until 2003 with the underlying assumptions. Based on the conclusions from these studies, a further look is taken into more recently published potential studies. Starting from [Berndes et al., 2003] an overview is given of the results, discussions and conclusions of this paper. We will analyse if the other studies did take into account the remarks posted by [Berndes et al., 2003] and if this will have a great influence or give another insight in their conclusions.

Other studies that have been analysed in this report are studies with more unique recent information. Many studies [e.g. Van den Broek, 2003; Hamelinck et al., 2004b; Enguídanos et al., 2000a, 2000b] are based on other potential studies and will therefore not be considered in this report. Although more studies are available in literature, only the studies with an own potential and those that cover at least the EU15 region are taken into the analysis:

- World:
  - Hoogwijk et al., 2003
  - Bauen et al., 2004 (OECD countries)
  - Hoogwijk et al., 2005
- EU:
  - Nikolaou et al., 2003
  - Kavalov 2004
  - Siemons et al., 2004
  - Ericsson et al., 2005

Worldwide potential

Berndes et al [2003] divide the analysed studies into two main categories:

- Demand-driven assessments that analysed the competitiveness of biomass-based electricity and bio-fuels, or estimated the amount of biomass required to meet exogenous targets on climate-neutral energy supply (demand side)
- Resource-focused assessments that focused on the total bio-energy resource base and the competition between different uses of the resources (supply side).

Figure 2-3 [Berndes et al., 2003] shows the wide variance in bio-energy potential according to the different investigated studies. For the demand driven studies, Figure 2-4 [Berndes et al.,

2003] gives the contribution of the biomass to the global primary energy supply. For the year 2050, the lowest estimate is 47 EJ/yr and the highest is about 450 EJ/yr.
Some general conclusions/remarks are drawn for this study:

- Global bio-energy supply and relative importance of biomass in the future global primary energy supply: the difference in estimates of future bio-energy potential ranges between larger than the present global primary energy demand and down to 1/9th of this for the year 2050.
- Regional bio-energy supply: developing countries are expected to contribute the major share of the global bio-energy supply in most of the studies, specially in the longer term (in 1 study Africa produces more bio-energy than it consumes, and will therefore be a net exporter of energy).
- Contribution of specific biomass sources to the total bio-energy supply: biomass plantations are considered to have the most important contribution to the total bioenergy supply in most of the studies.

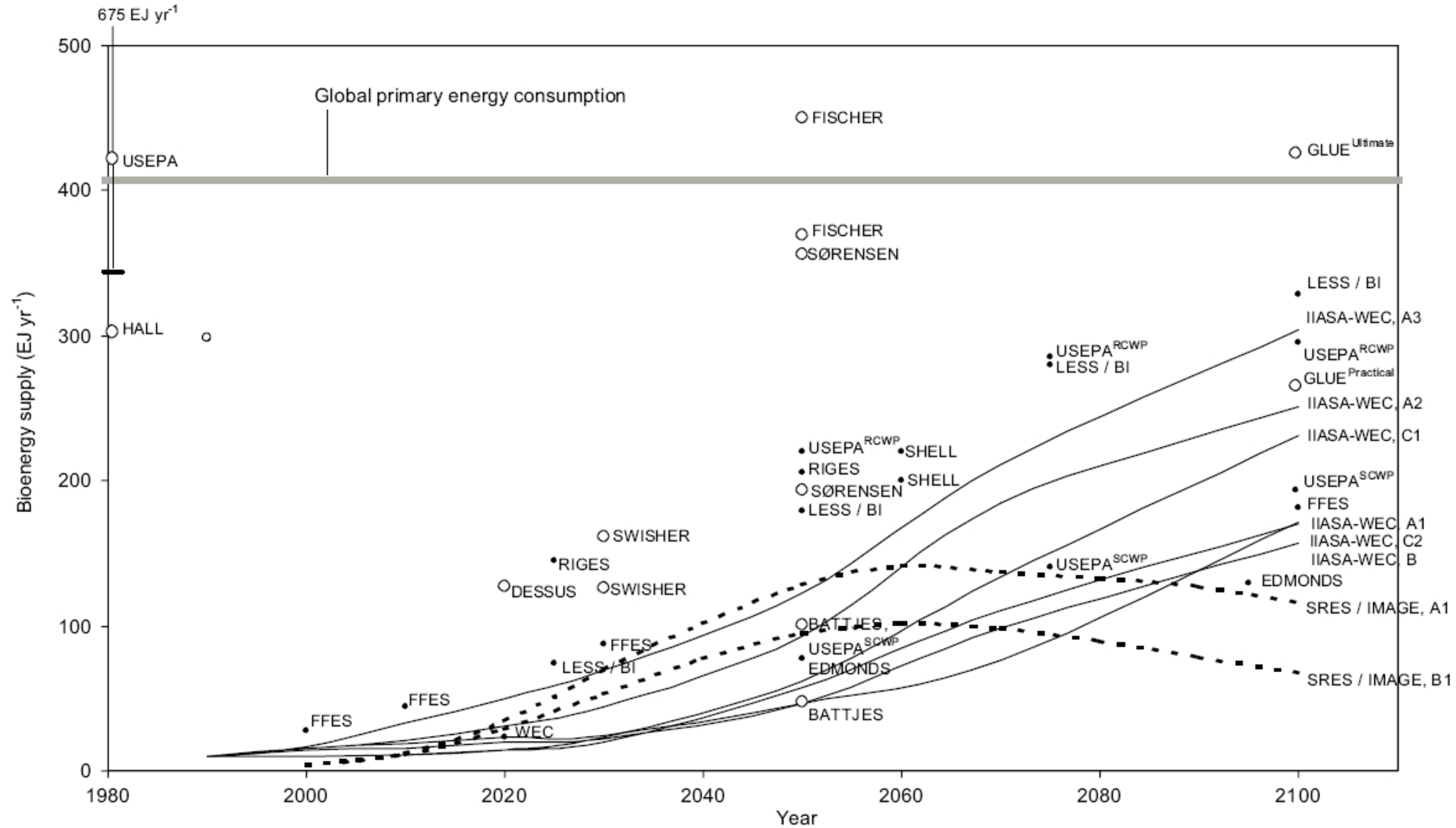

Figure 2-3: Worldwide potential biomass for energy over time. Resource-focused studies are represented by hollow circles and demand-driven studies are represented by filled circles. USEPA and HALL, who do not refer to any specific time, are placed at the left side of the diagram. IIASA-WEC and SRES/IMAGE are represented by solid and dashed lines respectively, with scenario variant names given without brackets at the right end of each line [Berndes et al., 2003]

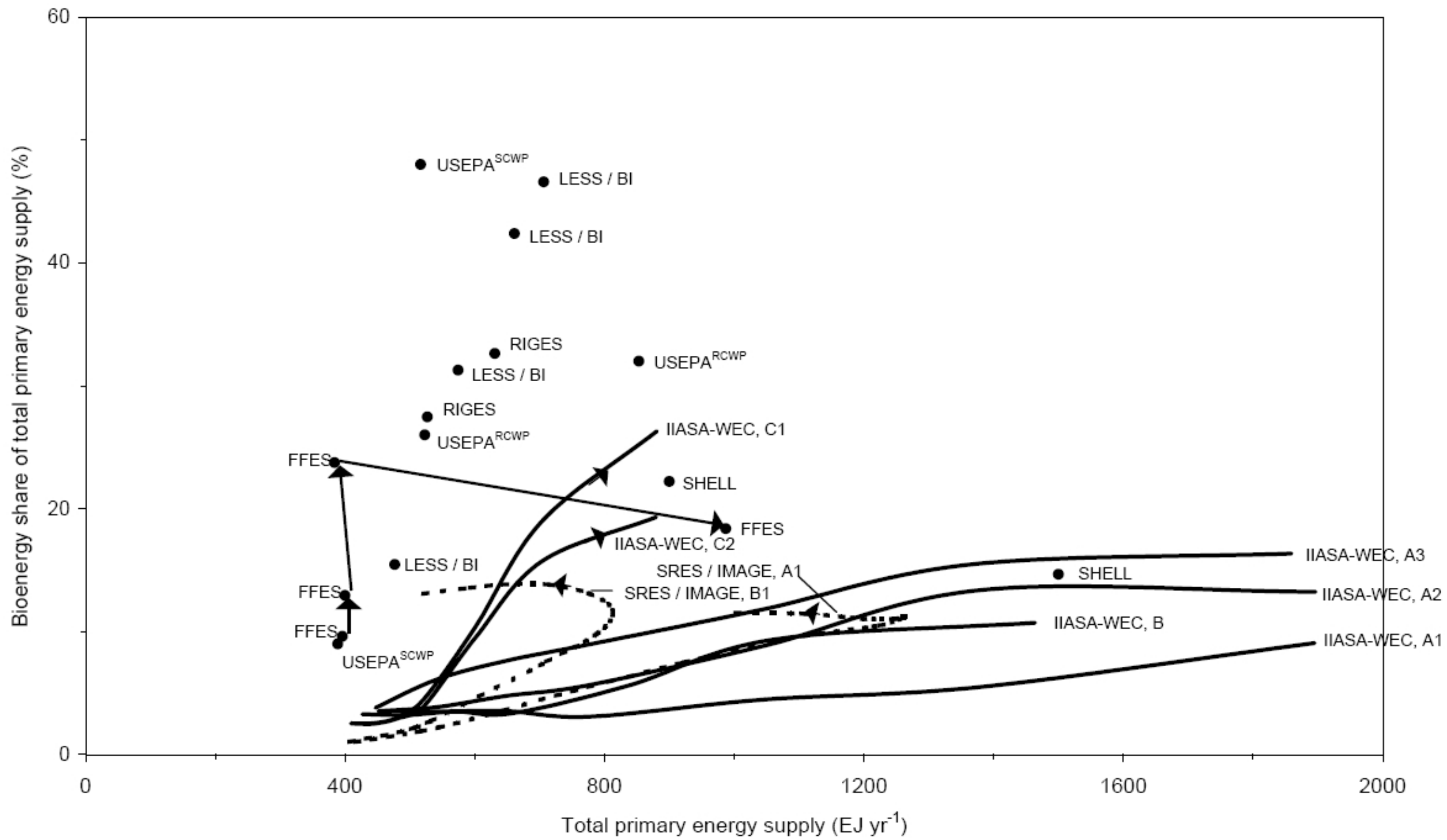

Figure 2-4: Total primary energy supply, and share provided from biomass in demand-driven studies. Where no indication of development is made for a particular study, the changes over time are towards increasing total primary energy supply and bioenergy share. IIASA-WEC and SRES/IMAGE are represented by solid and dashed lines, respectively, with scenario variant names given without brackets at the right end of each line [Berndes et al., 2003]

Potential in de the EU 2010

The study made by Palmers et al [2004] looked at 5 studies to estimate the biomass potential in Europe: [Teres II, 1997], [Hall, 1993], [Biewinga et al., 1996], [WEC, 1994], [Dessus, 1991], [NTUA, 2003] and [EC, 2003]. The implementation of the biofuels directive has the consequence that the total European demand for biomass for energy purposes (both electricity and transportation fuels) is about 60% of the total estimated technical potential indigenous biomass availability in 2010 in the EU25 (Figure 2-5). The middle part of the figure presents the best estimate as used in this study and the right side of the figure presents the estimated demand for biomass for biofuels and bioelectricity purposes for the year 2005 and 2010. For electricity the indicate country based EC targets are used. However, it is also clear that there is still much uncertainty in the assessment of the technical biomass potential within the EU25. This is especially the case regarding the AC10, of which current estimates are expected to be relatively modest.

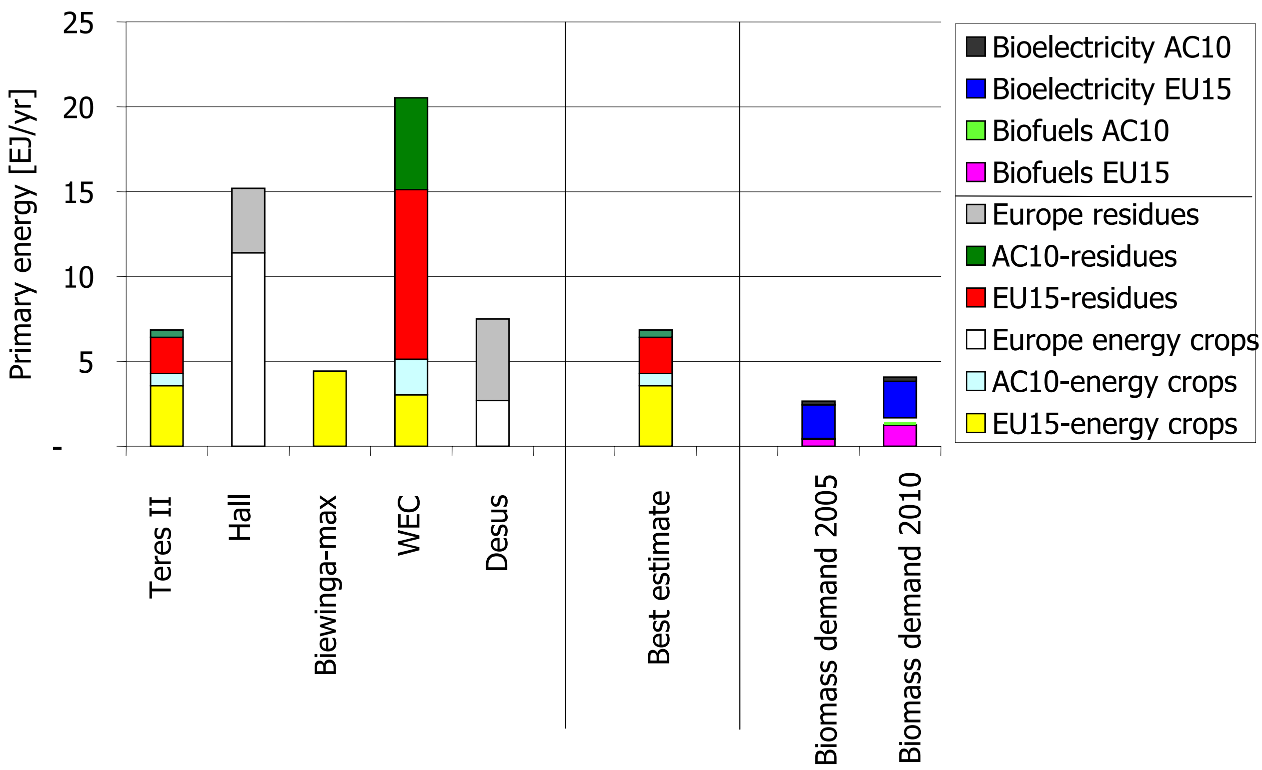

Figure 2-5: The potential biomass availability of the EU15, AC10 (10 Accession Countries) and/or Europe according to 5 studies (left part of the figure) [Palmers et al., 2004]

From Figure 2-5 it can be concluded that the biomass demand in Europe in the year 2005 for the production of electricity and heat may not necessarily lead to import of large quantities of biomass. The biomass demand can probably be covered with biomass of EU origin. In the year 2010 implementation of the biofuel directive has as consequence that the total European demand for biomass for energy purposes is about 60% of the total estimated technical potential biomass availability in 2010 in the EU25.

The demand for other uses of biomass resources (e.g. material) adds up to this figure, and will put further pressure to import biomass from outside the current EU.

General discussion and conclusions

Biomass plantations

Although there are widely different biomass plantation areas and yields considered between the various studies, most of them consider a substantially increase in the overall global plantation area which would imply very ambitious planting rates.

Utilisation of forest wood for energy

Bio-energy from forest are calculated on different ways: from the restriction of the utilisation of discarded wood-based products, (primary and secondary residues in the forest sector) to the potential based on forests biomass growths.

Residue generation and recoverability

The estimated amounts of residues in the food and forest sectors are substantial in a global energy context.

Interactions with other biomass and land uses

The development of food and material sector is exogenously defined in most studies, with the bio-energy sector evolving in parallel, utilising residues and land not required for food or materials. The expanding bio-energy sector does by definition not affect the food and material sector in most studies.

Difference in total bio-energy

From demand-driven studies it can be concluded that bio-energy demand can increase to several hundred EJ per year in the near future, where resource-focussed studies widely differ in the conclusion on how much biomass could be available in the future. Two crucial parameters can be pointed out to explain this divergence in the studies: land availability and yield levels in energy crop production, which are very uncertain.
The divergence in the future availability of forest wood and residues from agriculture and forestry in these studies can be explained by the different approaches to estimate the potential: the lower-end estimates restrict the bio-energy potential to certain shares of the wood flows in the forest sector (and thus to the future forest product demand), while the higher end estimates does not make such restrictions.

Feasibility, but at what cost?

The studies illustrate how a future large-scale and technically feasible bio-energy supply could look like. Based on the review it was however not possible to see the social impact, nor if this would be an attractive option for climate change mitigation in the energy sector. Those studies miss therefore the interaction of the expanding bio-energy sector with other land uses. Moreover, the environmental consequences of a realisation of the assessed bio-energy potentials are insufficiently analysed.

Other recent studies

Starting from the overview of the studies in the previous paragraph, more recent studies will now be analysed, with the focus on the following items:

- Driver: Are the studies demand driven or resources focussed?
- What are the assumptions for bio-energy plantations concerning:

    - Land availability
    - Yields of the energy crops
- Concerning bio-energy from forests: are only wood residues taken into account are also growth of the forests?
- Did the study take into account the interaction with:
    - Materials
    - Other land use (food)

Review of the studies concerning the world potential

The study made by Hoogwijk et al. [2003] takes into consideration the remarks made in [Berndes et al., 2003] and puts more emphasis on the interaction to the competing biomass use for materials. A scenario for food supply and demand is given, with the implications for the future land requirement for this food production. This study also makes use of a wide variety of existing studies and identifies six biomass resource categories for energy: energy crops on surplus cropland, energy crops on degraded land, agricultural residues, forest residues, animal manure and organic wastes. The study takes into account the land availability and the yield. The main conclusion of the study is that the range of the global potential of primary biomass (in about 50 years) is extremely broad with 33 to 1135 EJ/year. This extreme disparity can be explained by lack of attention to the different types of potentials as explained in the previous sections.

The study made by Bauen et al. [2004] was prepared for WWF and evaluates the potential for sustainable power production from biomass and its contribution to the reduction of CO_2 emissions in the medium term (2020). This study focuses on OECD countries. This report does not consider municipal solid waste or organic industrial waste as biomass, but residues from crop growth and forestry are considered as biomass. Three types of biomass are considered, as potential, a percentage of the potential from other studies is given. It is not clear what are the underlying assumptions. The total potential for 2020 for the world is estimated:

- for residues from non-energy production activities; 17.5EJ (25% of the use of the current residues)
- for dedicated biomass production for energy and utilisable fuelwood from multi-purpose forests, 42.5 EJ, 5% of OECD crop, forest and wood land with an average yield of 10 tonne dry biomass/ha

The study made by Hoogwijk et al. [2005] analysed the geographical and technical potential of energy crops for the years 2050–2100 for three land-use categories: abandoned agricultural land, low-productivity land and 'rest land', i.e. remaining non-productive land. The study envisages development paths using four scenarios resulting from different future land-use patterns that were developed by the Intergovernmental Panel on Climate Change in its Special Report on Emission Scenarios. The world land availability is modelled by grid cells of 0.5° by 0.5° in this model. The geographical potential of abandoned agricultural land is the largest contributor. For the year 2050 the geographical potential of abandoned land ranges from about 130 to 410 EJ per year.

Review of the studies concerning the EU potential

The study made by Nikolaou et al. [2003] gives an analysis of the sectors that serve as biomass suppliers; agriculture (residues, livestock waste and energy crops), forestry (fuel and residues), industry (residues) and waste. The resource assessment was done in three steps;

technical resource potential is the total annual production of all sources, given no restrictions; the available resource potential per land takes estimated realistic limits into account, such as, physical, environmental, agronomic, sylvicultural and economic; the energy potential is then estimated on the gross caloric value. All the estimates were done, based on the year 2000.

Kavalov et al. [2003] assessed the land area requirements to meet the transport bio-fuels targets within the EU 25 and the EU 27. The timeframe is restricted until 2010 and the focus is on agriculture derived production of biofuels only. Only bio-ethanol from wheat, potato or sugar beet and biodiesel from sunflower or rapeseed are considered. The study takes into account different possible yields for the crops and the possible potential in the New Acceding Countries and the Candidate Countries is based on two variants: the current potential which is the summary of the national Forecasts and the optimal Technical potential, determined in previous studies.

Siemons et al. [2004] produced a report for the European Commission and had as goal to provide reliable and realistic data on bio-energy's contribution to the EU energy market by 2010 and 2020, while taking into consideration the various policy instruments such the Directive on RES-Electricity, the Directive for renewable fuels (including bio-fuels) for transport as well as bio-energy's contribution to achieving the EU's Kyoto commitments. This study takes into account: the demand for renewable energy, the supply of biomass and also the technical development. The same method as in [Nikolaou et al., 2003] was used but more insights on the assumptions were given. Biomass supply is directly related to the use of it: making heat, power or transport fuels. In this study shows only the amount of bio-ethanol and biodiesel that can be obtained if the current available bio-crops are transformed into these fuels.

Ericsson et al. [2005] used a resource-focussed approach to assess the short-, moderate- and long-term potential of biomass to energy in 5 scenarios. Biomass that is considered is: forestry residues, forest industry by-products, straw, maize residues and energy crops. The scenarios are based on assumptions regarding residue harvests, energy-crop yields and surplus agricultural land. Energy crop yields are correlated with the national wheat yields, a methodology not seen in biomass assessments before. The assessments show that under certain restrictions on land availability, the potential supply of biomass energy amounts to up to 11.7 EJ/year in the EU15 and 5.5 EJ/year in the ACC10.

3 SELECTED BIOMASS ROUTES

3.1 Introduction

Figure 3-1 summarizes most of the possible routes to replace fossil fuels by bio-fuels in both automotive and heat & power applications, with exclusion of hydrogen production for fuel cells and some other more exotic potential applications. The analysis has considered only a limited number of potential routes which are considered as relevant for the present study (indicated in fat lines). Within the considered routes, some are still in the demonstration phase but are considered to be of importance in the medium term (Fisher-Tropsch and wood hydrolysis). It was decided not to further study biogas, hydrogen and DME. Both hydrogen and DME will most likely not be available before 2050, which is a time frame beyond the present study. Biogas is suspected to be of little importance for automotive application in Belgium and was therefore also not selected. It is finally to be observed that liquid fuels obtained from biomass can be (and effectively are) used in heat and power applications, but these routes will not be considered because what happens downstream of the liquid fuel production is not really relevant.

Each selected route consists of a 'chain' of actions starting from the production till end-use. The chain selection is discussed more in detail in the subsequent sections. Detailed data about the full chains can be found in the annexes (see also Chapters 5 and 6).

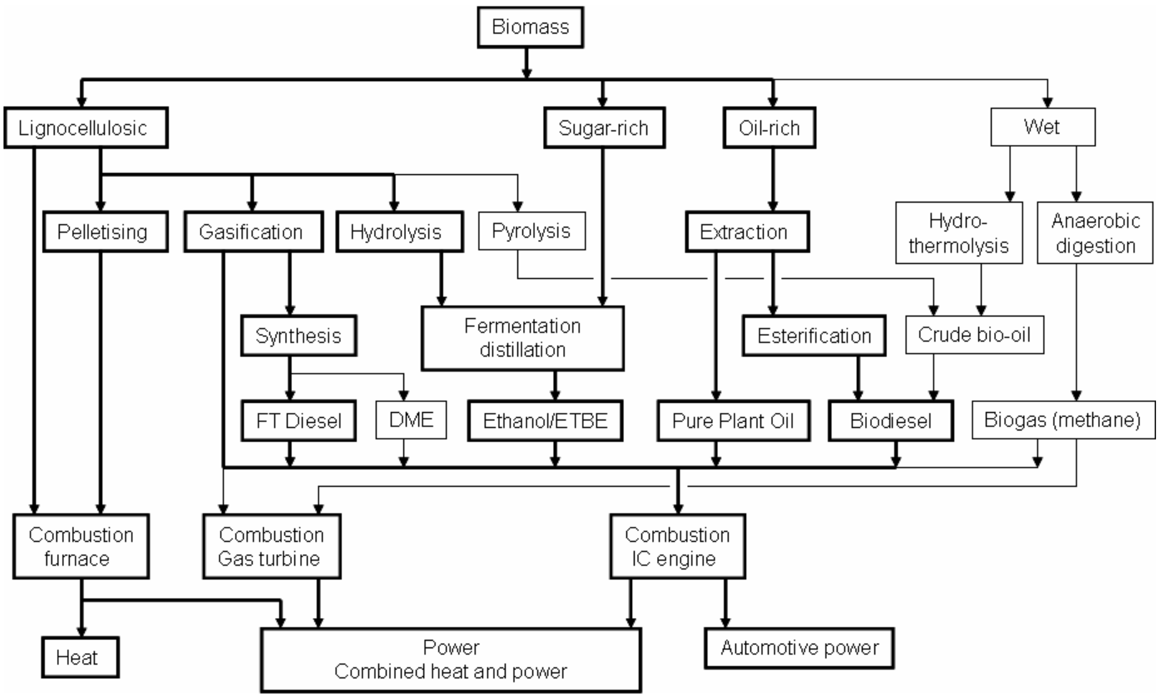

Figure 3-1: Summary of biomass utilisation routes, with exclusion of hydrogen and fuel cells. Fat lines are considered within the present study

3.2 Chain 1 : Pure plant oil for automotive application

The use of pure plant oil or PPO is yet marginal but will be investigated owing to its potential. PPO can be obtained from a wide range of oleaginous crops. The most common used crops are rapeseed, soybean and sunflower. Some other crops used for PPO production, in tropical and subtropical regions are palm trees, *Jatropha curcas* L. or purging nut (*Euphorbiaceae*). Today, waste vegetable oils can also be used for the production of PPO or biodiesel. These waste oils were traditionally used as an animal feed component. This is now being avoided mainly due to the risks of contamination of the food chain and public health problems. They have the advantage of being a readily available waste product, though thorough cleaning is necessary to remove contaminants that would quickly block fuel filters or damage the engine fuel system.

Chain 1 considers decentralized PPO production from locally produced rapeseed for use as bio-fuel for road transport, replacing fossil diesel fuel, used pure (100%) in adapted engines. The decentral process capacity is less than 1,000 tons/year and requires no transport to a large centralized conversion plant. The decentralized production process of vegetable fuel oil requires only a press, space and electricity. The production capacities are relatively small, which implies the development of niche markets with not many new jobs created. However, the return of the activity profits directly to the farmer(s). The production of PPO is a mature technology consisting of pressing, settling, filtering and storage. The majority of vehicles running on PPO are converted diesel vehicles and, in theory, most diesel engines can be converted to PPO operation. According to the French PPO association [Marty, 2004], up to 50% PPO can be blended into diesel without any engine adaptations. When running on pure PPO (100%), the engine must however be adapted. The distribution is local with dedicated pumps.

The quality of the oil is very important in order to guarantee the correct operation of the vehicles, in particular the injectors, piston rings and lubrication oil stability. As for today, the only available standard is the German standard DIN 51 605. The viscosity of the oil is a parameter to consider, and this is why running on pure PPO requires adaptations (preheating system, single or double reservoir adaptation).

The ratio between saved and consumed fossil fuel for PPO used as a motor fuel is commonly said to vary between 2.9 and 4.7 [Jossart et al., 2005]. This results from the fact that the transportation of raw material and final products is reduced to a minimum and the process itself is less energy consuming. The data available in literature concerning the emission impact of PPO is very sketchy (no clarity about raw material, experimental conditions …). However, most authors agree there is a net reduction in CO_2 emissions (77%, Ecobilan 2002), there are virtually no SO_2 emissions. Doubt remains in the literature as for the CO, N and PM emissions. Energy and CO_2 aspects will be further discussed in Chapters 5 and 6.

3.3 Chain 2 : Biodiesel or RME from esterification

Biodiesel is a generic name for fuels obtained by esterification of a vegetable oil. It is defined by the Directive 2003/30/CE as "a methyl-ester produced from vegetable or animal oil, of diesel quality, to be used as biofuel". It can also be produced from recovered waste vegetable oils. Biodiesel is mainly derived from rapeseed oil in the northern part of Europe and from sunflower oil in the southern part. This report only considers biodiesel from rapeseed denoted as methyl ester or RME and from used vegetable oil.

Chain 2 considers biodiesel for automotive use, replacing fossil diesel fuel, used in a 5% blend or pure in adapted engines. The biodiesel is produced in 3 options:

- Chain 2a : centralised biodiesel production from locally produced rapeseed (1,000 and 10,000 t/yr)
- Chain 2b : centralized (> 10,000 t/yr) from imported rapeseed
- Chain 2c : centralized (> 10,000 t/yr) from imported rapeseed oil
- Chain 2d : centralised biodiesel production from used vegetable oil

The process of making biodiesel from vegetable oils is called transesterification and is a mature technology. The majority of the alkyl esters today are produced through a base catalyzed reaction with methanol. During esterification, the triglycerides (95% of the vegetable oils) react with methanol in the presence of a catalyst, usually sodium hydroxide (NaOH) or potassium hydroxide (KOH), resulting in the production of methyl esters. It is a rather cheap process as it occurs at low temperature (50-60°C) and pressure (1.38 bars) and it has a high conversion (98%) with minimal side reactions and reaction time [Van Thuijl et al., 2003]. Glycerine is the main byproduct and it can be used in many industrial applications such as paints, cosmetics a.o. The EN 14 214 standard applies to biodiesel.

Unless for the latest versions (late 1990's), most vehicles are not suited for using pure biodiesel. The problem is the durability of the plastic and rubber components, which come into contact with the fuel and, with time, dissolve or corrode and leak. Tests have shown that blends diesel/biodiesel up to 30% of biodiesel on a volumetric base can be used with no modifications to the engine, with performances similar to fossil diesel and with negligible differences of the fuel consumption. The life of the engine was not affected either, the wear of the engine was similar and particular procedures of maintenance were not requested [Chiaramonti et al., 2003]. When biodiesel is blended, the regular diesel distribution network can be used. Pure biodiesel requires however separate pumps [Shumaker et al., 2003].

The ratio between saved and consumed fossil fuel for biodiesel varies between 2.0 and 3.0. The oxygen contained in biodiesel causes CO emissions to decrease by 15-20% [Ecobilan, 2002]. On a well-to-wheel basis, biodiesel reduces CO_2 emissions by 70% [Ecobilan, 2002]. NO_x emissions, however, tend to increase, especially due to the use of fertilizers during crop growing. Energy and CO_2 aspects will be further discussed in Chapters 5 and 6.

3.4 Chain 3 : Bioethanol from wheat, sugar beet and wood

Bioethanol is a fermentation ethyl alcohol. Any type of biomass that contains appreciable amounts of sugar or material that can be converted into sugar such as starch is suitable for ethanol production (sugar cane, sugar beet, molasses, wheat, corn, barley, oat, sweet sorghum, potatoes, rice …). Starch has to be converted into simple sugars before processing.

Processing solid biomass containing cellulose and hemicellulose can also produce ethanol. Such feedstock include short rotation energy crops (willow, poplar, miscanthus …), agricultural residues (straw, maize stalks, rice hulls …), forest residues, waste wood, municipal wastes (yard and used paper), industrial waste (pulp/paper and sludge) etc. Ethanol can be further transformed into ETBE (Ethyl-Tertio-Butyl Ether) by adding isobutylene (fossil fuel). It is used as a gasoline additive to enhance its octane rating and is an alternative to the toxic MTBE.

Chain 3 considers ethanol for use as biofuel for road transport, replacing fossil gasoline, used in a 5% blend or further transformed into ETBE to replace MTBE, from four different resources:

- Chain 3al : centralized ethanol production from locally produced wheat
- Chain 3ai : centralized ethanol production from imported wheat
- Chain 3b : centralized ethanol production from locally produced sugar beet
- Chain 3c : imported ethanol from sugar cane
- Chain 3d : centralized ethanol production from locally produced wood
- Chain 3e : centralized production from imported wood

Different conversion processes exist for ethanol production. The most energy intensive part of the process – fermentation and ethanol recovery – is the same for all raw materials. Where the individual processes differ, is in the extraction and preparation of fermentable carbohydrates. The main components of an ethanol plant enclose: raw material receiving and preparation of the fermentable carbohydrates; fermentation; distillation.

Ethanol from winter wheat is obtained either through wet or dry milling. Both wet and dry milling produce among others CO_2 (recycled) and a protein-rich animal feed ingredient (DDGS - Dried Distillers Grains Soluble). Ethanol from sugar beet is obtained by mixing hot water with beet lamellas to extract the sugar by diffusion. Lamella residues are pressed to extract the remaining water form the pulps. The pulps are used mainly for animal feeding. The sugar containing juice is cooled and transferred to fermenters in which yeast convert the sugars to ethanol and carbon dioxide. The ethanol is recovered through distillation. The production of ethanol from sugar and starch containing crops is a mature technology.

When lignocellulosic biomass is used, an extensive process is required for the extraction and fermentation of the cellulose and hemicellulose. Unlike traditional ethanol feedstocks, the cellulosic materials cannot be fermented into ethanol by Saccharomyces cerevisiae yeast used by industry to produce ethanol. Recently, special micro-organisms have been genetically engineered which can ferment C5 (hemicellulose) sugars into ethanol with relatively high efficiency [Badger, 2002]. Some can even ferment both C5 and C6 sugars into ethanol. Bacteria have drawn special attention from researchers as they can ferment in minutes as compared to hours for yeast. It is only recently, though, that cost-effective technologies for producing ethanol from cellulose have started to emerge. Ethanol from cellulose holds great potential due to the widespread availability, abundance and relatively low cost of cellulosic materials [Badger, 2002].

Ethanol can be used in three different ways in current spark ignition engines: blended with gasoline in low (5 to 20%) or high (85%) proportions; blended with gasoline as ETBE (10-15%); pure (hydrous). When ethanol is mixed with gasoline up to 20%, no engine or infrastructure adaptations are required. However, in practice, car manufacturers do not recommend the use of gasoline blends with more than 10% content of ethanol and the European standard EN 228 for gasoline does not allow more than 5%v of ethanol blended. In some countries however (USA, Brazil, Sweden), adapted engines called "flexible fuel" are currently available for the use of high ethanol blends (E85). If it is used in high concentrations, ethanol corrodes certain kinds of plastics, elastomers (rubber) and metals like steel, aluminium and magnesium.

Ethanol can be further converted into ETBE (Ethyl-Tertio-Butyl Ether). It is produced by combining in the presence of heat and a catalyst, bioethanol (47%v) and isobutylene, a fossil fuel derivative (53%v) [Jossart et al., 2005]. For the European Union, 47%v is the percentage

by volume that is considered as biofuels. Blends up to 15% ETBE are allowed in the European Union (DIR 2003/30/CE). Many technical problems faced with ethanol can be solved by using ETBE. The superior octane rating of ETBE renders it very interesting for replacing components such as MTBE currently used in gasoline. Due to its low vapour pressure, ETBE-blended gasoline has a volatility that does not increase (http://www.chevron.com). Therefore, ETBE, as opposed to ethanol, does not cause problems regarding the fuel distribution network.
Both ethanol and ETBE are not yet standardized, but a European standard will most probably be available soon for ethanol blended in gasoline.

There is a great diversity in literature concerning the energy balance of ethanol. This is due to the fact that the energy balances heavily depend on the feedstock used, the extent of utilization of by-products and other specifics. We may affirm however, that the energy balance of ethanol is always positive and above one, which means that ethanol produces more renewable energy than is needed to produce it, using fossil energy (see Chapters 5 and 6). In the case of ETBE the difference must be made between the renewable part of ETBE (47%v) when making the energy balance. When using SPA (Chapter 6) this is however automatically done.

The energy balance may be improved mainly through a reduction of nitrogen fertilizers applied in the energy crop. Studies, carried out for ethanol, demonstrate significant energy efficiency improvements in ethanol production: higher yielding varieties, use of improved farming practices (precision and no-till farming) and technological advances in ethanol production such as new bio-technology tools to improve enzymes and fermenting organisms [Enguídanos et al., 2002a].

Oxygenates, such as ethanol, influence the exhaust emissions primarily by their effect on the balance of fuel and air in the engine. If a car, tuned to run on gasoline, is run on fuel containing ethanol without readjustment, the effective air-fuel ratio will be increased as a result of the oxygen contained in the fuel, at least for older model cars. Modern adaptive learning vehicles will compensate to some extent, so the effects of a change in fuel may not be so large. The leaner air-fuel ratio will tend to reduce CO and hydrocarbon emissions, but in some cases at the expense of an increase in NO_x [CONCAWE, 1995]. CO_2 emissions are reduced by ~ 60% [Ecobilan, 2002].

Ethanol is not yet readily available on the European market. Some non-technological limiting factors are feedstock prices, ethanol production costs, oil prices and taxation of energy products [Enguídanos et al., 2002a]. The main advantage of ethanol and ETBE as an outlet for arable crops is that it can be produced from several types of feedstock, many of which are already being grown. Production, harvesting, drying and storage are technologies already available both for sugar beet and for wheat in Belgium. The feedstock prices account for 55-80% of the final price of ethanol [Van Thuijl et al., 2003]. The efficiency of the process is nearing its limit and significant cost reductions will thus not occur. Research is therefore focusing on the ability to produce ethanol from lower-cost biomass such as cellulose.

3.5 Chain 4 : BTL or Biodiesel from Fischer-Tropsch synthesis

The biomass-to-liquid (BTL of FT Diesel) fuel is a synthetic fuel. Biomass is converted to a liquid fuel through indirect liquefaction, whereby the biomass is first gasified, followed by the conversion of the formed synthesis gas to a liquid fuel, also called Fischer-Tropsch fuel. Any type of biomass can be used as a feedstock, including lignocellulosic materials such as crop residues (straw, maize stalks, molasses …), grasses or wood. Wet biomass, like municipal solid waste and some agricultural residues can be used as well, but this results in a lower efficiency.

Chain 4 considers BTL for road transport, replacing fossil diesel fuel, used in a 5% blend or pure (100%) in adapted engines. Two variants consider locally produced wood and imported wood :

- Chain 4a : centralized BTL production from locally produced wood
- Chain 4b : centralized BTL production from imported wood

The gasification process of biomass results in a mixture of combustible gases commonly called syngas, rich in H_2 and CO. It is composed of light hydrocarbons ($C_{1 \text{ and } 2}$), LPG ($C_{3 \text{ and } 4}$), naphtha (C_{5-11}), diesel (C_{9-20}) and wax (> C20). Besides these straight-chain hydrocarbons, small amounts of contaminants are present, such as branched hydrocarbons, chlorides, sulphur, alkali metals, nitrogen compounds and tars... These need to be removed before the syngas can enter the reactor where the FT reaction takes place. The distribution of the products is determined by the process parameters (temperature, pressure), the reactor type and the catalyst used. Typical reaction conditions are temperatures between 200 and 250°C and pressure ranges from 25 to 60 bar [Dry, 1981]. These conditions can be adapted and selected to produce hydrocarbons of specific lengths. If the process is operated at higher temperatures, it mainly produces lighter hydrocarbons, which can be refined to petrol and diesel, solvents and olefins. However, higher yields can be obtained when the process is optimized towards the production of wax. The wax can be selectively cracked to yield predominantly diesel. Additional hydrogen is required for this hydro-cracking, which can be produced from a syngas side-stream that is completely shifted to hydrogen via the catalytic water-gas shift reaction.

The Fischer-Tropsch process is an established technology and commercially available for fossil fuels, but not for biomass fuels. The most critical step in the integration of biomass gasification and the FT synthesis is the cleaning of the bio-syngas. Some impurities such as S and N containing compounds can be removed with available techniques, though designed for other processes. For other impurities, specific to bio-syngas such as tars, there is no available technology yet for their removal. Commercial BTL plants are not expected before 2010.

BTL can easily be mixed with fossil diesel and can thus be applied in current diesel engines and the existing diesel distribution network without any specific adaptations. However, special formulations or additive packages may be necessary to meet standards to fuel lubricity, cold flow, and elastomer compatibility [May et al., 2001]. The oxygen contained in BTL causes CO emissions to decrease due to better combustion. The GHG emissions for biomass-based FT fuels are very low, as the carbon contained in biomass is recycled between the atmosphere and the fuel.

According to Hamelinck [2004a], BTL could be produced at 16.1 €/GJ with current technologies (400 MW_{th} input), which is still about four times the production costs of low-sulphur fossil diesel. The collective effect of large scale, technological learning and selective catalysts may bring the BTL costs down to 9 €/GJ.

3.6 Chains 5 to 9 : Wood used for heat and/or power production

As stated before, wood for automotive application is a promising route, both in terms of surface requirement, efficiency and CO_2 reduction potential (see Chapters 5 and 6). The technologies are however still in a development phase, whereas wood is also a primary choice for other fossil replacement through power and/or (not to be forgotten!) heat. The wood is therefore put into competition with automotive application through extra chains, as follows

- Chain 5a : Pure heat production from locally produced wood
- Chain 6a : Combined heat and power production from locally produced wood through an Organic Rankine Cycle (ORC)
- Chain 7a : Combined heat and power production from locally produced wood through fixed bed gasification and piston engine
- Chain 8a : Pure power production through co-combustion in a coal plant
- Chain 9a : Pure power production in a small scale steam power plant.

Chains 5b to 9b consider the same applications but using imported wood rather than locally produced wood.

Pure heat production

Biomass boilers are relatively cheap (about 250 euro per installed kW_{th}, regardless of the size). Good combustion technology allows to use biomass (wood in particular) with low emissions and acceptable economy. The efficiency of biomass boilers is moreover not significantly lower than oil and gas boilers, especially in the MW_{th} scale and with use of condensing boilers where LHV efficiencies near 100% are observed [Novak et al., 2005].

CHP : organic Rankine cycle [1-1.5 MW_e range]:

The Organic Rankine Cycle (ORC) operates with a same principle as the conventional Steam Rankine cycle, but with organic fluid (propanol, isobutene, …) as a working medium instead of steam. ORC is of interest in power scales below 2 MW_e, where steam turbines become too small and inefficient. The vapour expansion is moreover a dry expansion, against wet expansion in steam. This allows the use of a regenerator between expander and condensor, which contributes to relatively good electric efficiencies at that scale. ORC's are suitable for electricity or CHP production from any solid, liquid of gaseous fuels, but they are especially suitable for biomass end waste heat applications. ORC are readily available and are very reliable. With condensing boilers global LHV energy usage around 100% is observed. Electric efficiencies are in the range of 18%, which is low but justifiable in high efficient CHP application [Novak et al., 2005].

CHP : fixed bed gasifier with piston engine [600 kW_e range]:

A fixed bed, down draft gasifier combined with a piston engine is at present the sole nearly commercial available system for small-scale electricity and CHP production, with use of internal combustion machinery. This is mainly because down draft gasifiers are atmospheric and do not produce large amounts of tar, which limits the cost of the gas cleaning for rather tolerant IC engines. Electric efficiencies seem to be relatively high (up to 30%), which is a major advantage. Global CHP efficiencies are at present not excessively high, but not enough experience is available to draw conclusions. Several installations are in operation in Belgium in a pre-commercial phase [Novak et al., 2005].

Power : co-combustion in steam power plant [large scale]:

The steam cycle is the most common way for electricity and CHP production from solid fuels, and co-combustion of coal with solid biomass is one of the most successful biomass applications so far, at least in the large scale. In co-combustion the biomass can take advantage of the higher steam qualities produced when using coal. Steam conditions are poorer when using pure biomass because of hot corrosion problems, which limit the boiler wall temperatures to 400-450°C. More research is thus needed to avoid corrosion in the super-heaters of the boiler and to increase the electrical efficiency by using higher steam conditions.

For pure electricity generation the steam is expanded to a very low pressure before it goes into a condenser, leading to efficiencies in the range of 35% in older subcritical plants to 45% or even more in advanced supercritical and ultra-supercritical plants. If CHP production is required, the steam condenses at a higher pressure in a water heater. With condensing boilers global LHV energy usage around 100% are observed. Electric efficiencies are in the range of 30%. Large scale CHP from co-combustion is however improbable in Belgium and only pure power production has been assumed (e.g. Ruien plant).

Power : combustion in a steam power plant [small scale]:

The last route considers power production from a small scale steam plant, using pure biomass and without any heat production. Efficiencies are poor because of poor steam conditions in smaller units, and the overall efficiency is also poor because of absence of heat production. Although such a scenario could be an option owing to the green power certificates, overall results in terms of efficient biomass use and CO_2 abatement are expected to be poor, which is confirmed by the results in Chapter 6.

3.7 Logistics of the biomass routes

Overall biofuel production systems include biomass production and harvesting (or collection) (P), transport to conversion site (T), conversion (C), transport to blending site (T), distribution (D) up to the final use (F) of the biofuel (Figure 3-2).

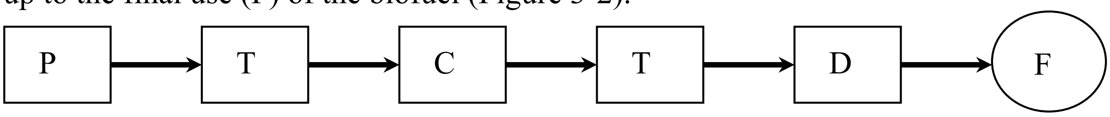

Figure 3-2: Schematic biofuel production chain

The biomass is transported from a specific production area to a conversion site, followed by the transport of the final product to a blending site. Finally, both the end products and the by-products are distributed to different places where there is a specific demand for those products. Biomass supply and logistics can therefore be defined as the links between the biomass potential in one area and the biomass demand in another area [Thrän, 2005].

According to Reesink [2005], 80% of the final price of raw biomass, which arrives at the conversion site, is linked to logistical aspects. Moreover, different biomass sources require different supply systems. Therefore, to develop well-adapted biomass logistics, the following parameters need to be taken into consideration:

- Energy content of the biomass and energy yield of a specific area
- Water content of the biomass
- Bulk density of the biomass
- Harvest window of the biomass

- Production plant capacity
- Location of the conversion site
- …

Properties of the biomass

Table 3-1 shows the energy contents, energy yields and typical water contents of the considered bio-fuels, as they are used in further analysis (see Annex A for more details). Energies are expressed as the Lower Heating Value (LHV) on a dry (or water free) base, yields are dry tons per ha and water contents are based on the total mass. Figure 3-3 illustrates the variety of water contents, in particular for wood where the water content varies from some 50% at harvest to 10% in the driest conditions. The water content of the biomass negatively influences the calorific value of that biomass and increases the costs of transport and storage. Both the calorific value and the storage conditions have a decisive impact on the choice of the harvesting time as well as on the transportation mode.

According to Table 3-1, the highest energy yield is obtained with sugar beet, but sugar beet has also the highest water content which hampers this advantage. Wood and wheat closely follow, whilst the energy from rapeseed has the lowest yield.

Table 3-1 : Basic properties of different biomass sources (as used, see Annex A)

Resource		LHV (GJ/dry ton)	Yield (dry ton/ha)	LHV yield (GJ/ha)	Water content (% total)
Winter wheat	Grain	17.0	8.8	150	16
	Straw	14.5	0.45	6.5	-
Sugar beet		16.7	15.4	257	75
Rapeseed	Grain	23.8	3.6	85	10
	Straw	16.5	-	-	-
Waste oils and fats		37.4	-	-	0
Wood		18.00	10	180	10-50

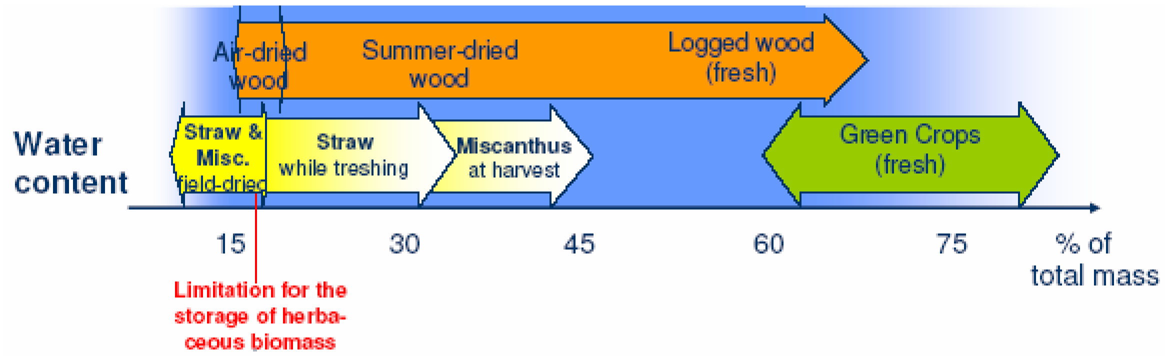

Figure 3-3: Water content of the biomass [Thrän, 2005]

The bulk density of the biomass is relevant for the transport options and needs for storage capacities. The bulk density depends however more on preparation (drying, cutting, pressing etc.) than on the biomass source itself.

The harvest window is the period in which the biomass is harvested on the field or in the forest. Solid biomass is typically harvested once a year, with the exception of forest residues which can of course be collected more than once a year. Storage capacities have to be designed with regard to the annual demand of the conversion plant.

Location of the conversion site

The location of the conversion site is important in order to guarantee a constant biomass supply and evacuation over time. If the biomass or the final products have to be stored, the storage capacity has to be planned. Moreover, the distribution facilities influence the location of the conversion site. Belgium has fortunately a very well developed distribution network with regards to road transport (Figure 3-4), railway transport (Figure 3-5) and water transport (Figure 3-6).

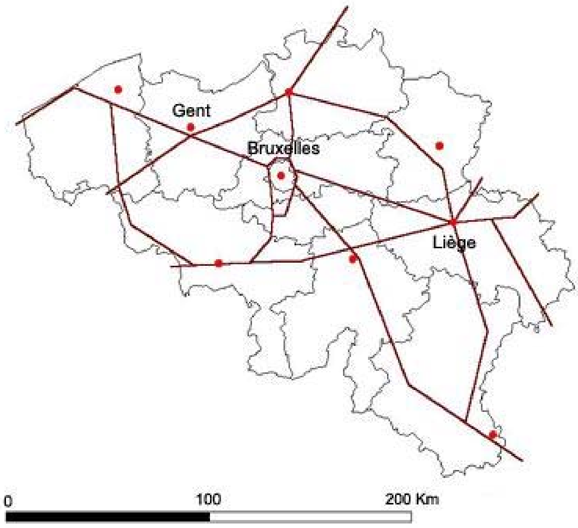

Figure 3-4: Belgian road network

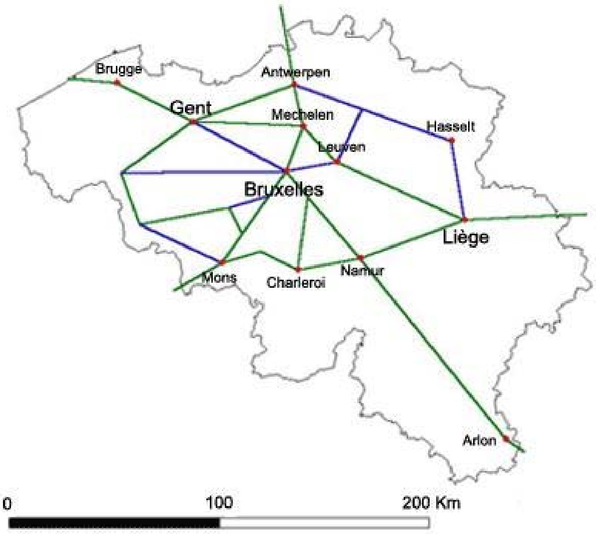

Figure 3-5: Belgian railway network

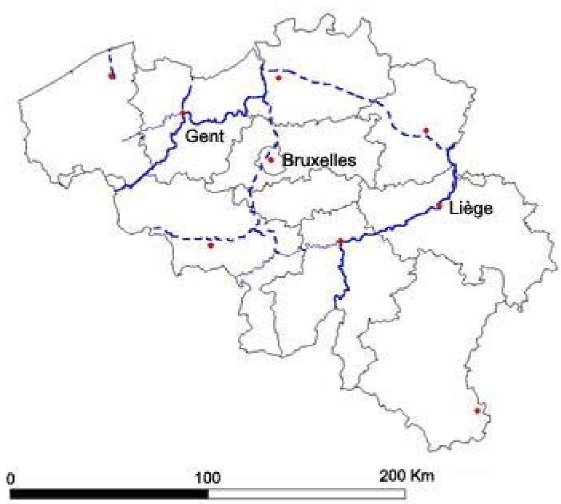

Figure 3.6: Belgian waterway network

Besides this well developed transport network, Belgian has important harbours such as the harbours of Ghent (maximum capacity of 12 000 tons; main harbour for agricultural bulk imports in Belgium), Antwerp (maximum capacity of 12 000 tons), Liège (maximum capacity of 12 000 tons) and Namur (maximum capacity of 3 000 tons).

In conclusion, Belgium has the required capabilities for supporting the biomass logistics. Based on this network, distances and transport capacities have been estimated for the different chains considered, and are detailed in Annex B.

Data for transportation types

Specific energy consumption for the three considered transportation types are given in Table 3-2. Associated costs and CO_2 emissions are automatically calculated in the analysis in Chapters 5 and 6.

Table 3-2 : data for transportation means

Transport type	Energy consumption (MJ/ton.km)	Fuel type
Truck	0.97	gasoil
Ship inshore	0.43	gasoil
Ship offshore	0.2	heavy fuel oil

Distribution and end-use

The distribution is realized by truck over a mean distance of 100 km, for all biofuel routes considered in the present study.

4 MACRO ECONOMIC ANALYSIS

4.1 Introduction

The selected fuels are analysed on their macro-economic impacts. This is done by input-output (IO) analysis. IO analysis is a partial analysis of the economy, concentrating on the production sector. It can be used to calculate what share of a certain expenditure will end up abroad and what share will end up as value added to the national economy [Van den Broek, 2000]. The sum of all value added in a country is the Gross Domestic Product (GDP). By means of input-output analysis, all indirect impacts can be modelled on the basis of the Input-Output table. This is an overview table of the economy of a country that shows which sector buys from which sector in order to produce its products. The Belgium IO table was delivered by the Federal Planning Bureau [www.plan.fgov.be]. In this study, IO analysis will be used to break the total cost of a biofuel and of its fossil competitor down into value added for Belgium, and imports.

On the basis of these results, estimates can be given as well on the direct and indirect employment generation from the production of biofuels as compared to the production of fossil fuels. The same accounts for the impact on the Belgium Treasury. A detailed description of the IO methodology applied in this study, with all steps undertaken, is presented in Annex G. Limitations of the application of the IO method for the analysis of bioenergy chains are discussed by Van den Broek [2000].

4.2 Results

Delivered costs

The delivered costs are presented in Figure 4-1 (on GJ basis). These costs are derived from data used elsewhere in this study, and broken down to relevant contributing components as reported in Annex H. The cost breakdown can also be divided into import and value added by means of the discussed input-output analysis. The result is shown in Figure 4-2, the two figures show the same total values, and the only difference is that the breakdown is expressed in another way.

Although we assume that some biofuels are domestically produced on set-aside land, the amount of import per GJ product decreases only slightly for biodiesel compared to fossil diesel: compare case 1 (PPO from Belgium rapeseed) and 2a (biodiesel from Belgium rapeseed) to the diesel reference. Implementation of some of the bioethanol cases leads to even a slight increase of import. This is best visible for cases 3b (bioethanol from Belgium sugar beets) and 3d (bioethanol from Belgium wood).

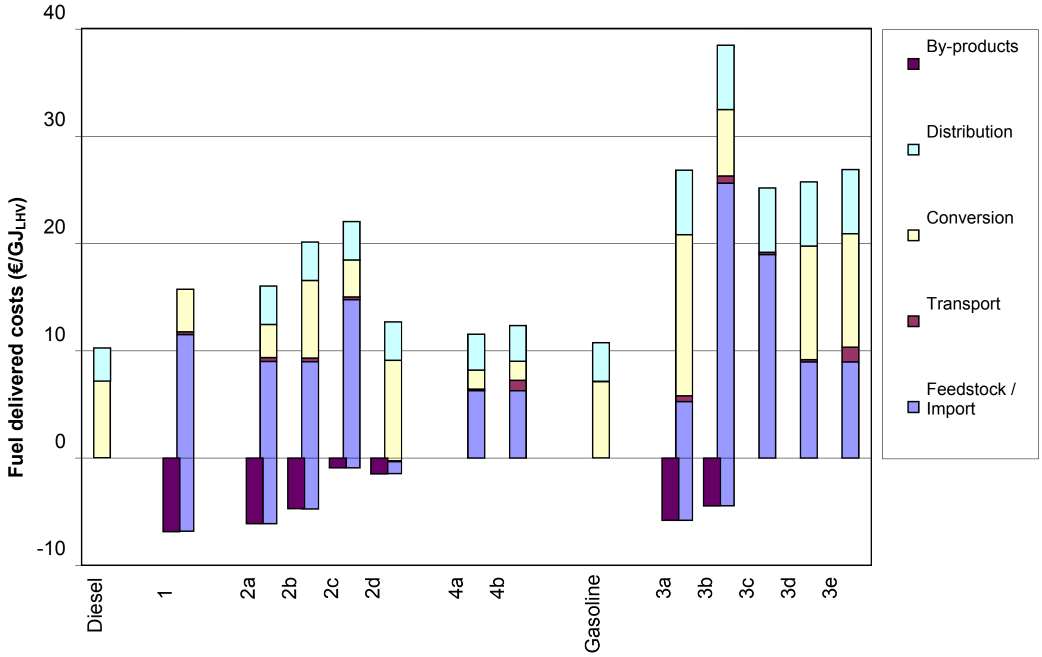

Figure 4-1: The fuel delivered costs at the gas station (€/GJ) broken down in different stages of the supply chain and compensating for by-product credits (negative contribution to the costs). The costs exclude excise duty and VAT.
See Table 5-1 for case description.

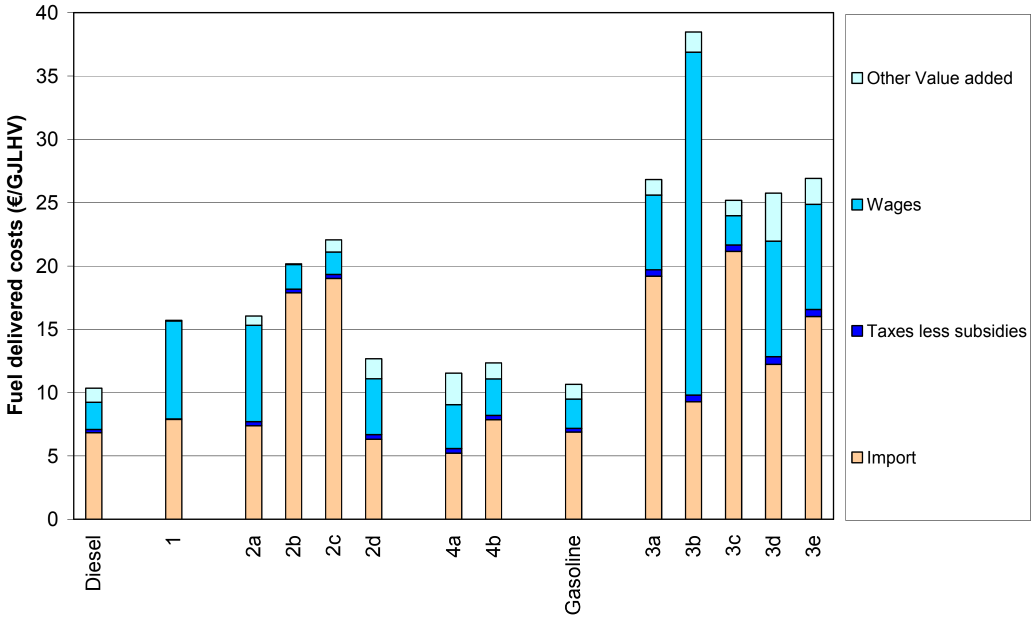

Figure 4-2: The fuel delivered costs at the gas station (€/GJ) broken down in import and value added: taxes less subsidies, wages, and other value added. See Table 5-1 for detailed case description.

These imports are caused by indirect imports from various sectors of the Belgium economy, for example the need for chemicals, additional energy, and also machinery itself (or the material it is made of) is probably for a certain part imported. The feedstock production and conversion, and the distribution of biofuels create much value added in the form of wages, because they are relatively labour intensive. Another breakdown can be given, showing indirect and direct import and value added to the Belgium economy (Figure 4-3). This figure clearly shows the considerable indirect imports in various biofuel supply chains that use Belgium feedstock.

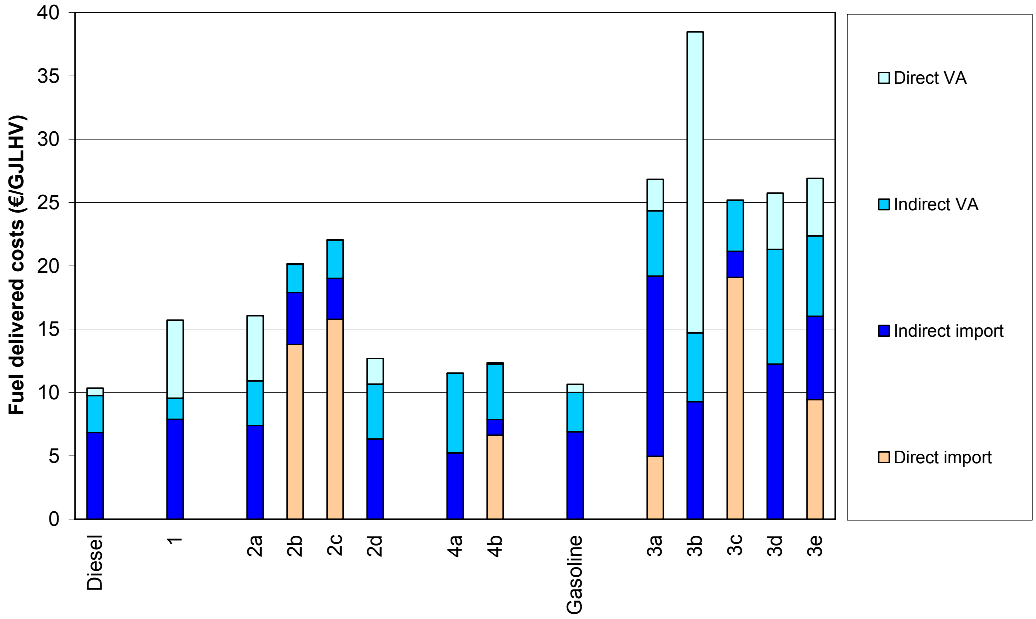

Figure 4-3: The fuel delivered costs at the gas station (€/GJ) broken down in indirect and direct import and value added. See Table 5-1 for case description.

When we compare between biofuels, we notice that in the biodiesel cases chains that require direct import of rapeseed (oil) from Poland or Canada (2b and 2c), require a much higher share of total imports than those using Belgium rapeseed or waste vegetable oil. Also for bioethanol supply chains the total imports are the lowest when Belgium sugar beets (3b) or wood (3d) is used.

Excise duty exemption to realize an equal GJ price

We assume that an excise duty exemption is granted by the government to biofuels that will lead to equal product prices per GJ compared to fossil biofuels. Only in this case we can assume that the amount of money spent on transportation fuels by consumers will remain unchanged. This assumption is necessary for a reliable input-output analysis, as alternatively a significant change in the consumers' expenditures would have other macro-economic effects that are not reflected within the IO table. Note that excise duty exemption to arrive at similar GJ prices means that litre prices of biofuels will be lower than that of fossil fuels, because the energy density of biofuels is smaller than their corresponding fossil fuels.

Figure 4-4 shows the results of this analysis. The total delivered costs for the various biodiesel options is the same 18.9 €/GJ (corresponding to 0.67 €/litre, excluding VAT, [www.petrolfed.be], and for gasoline and ethanol 27.2 €/GJ (0.88 €/l). Further, note that to arrive at equal GJ prices the amount of excise duty exemption required in some cases is larger than the current duty on the fossil fuels they replace (Figure 4-4: cases 2b, 2c and 3b).

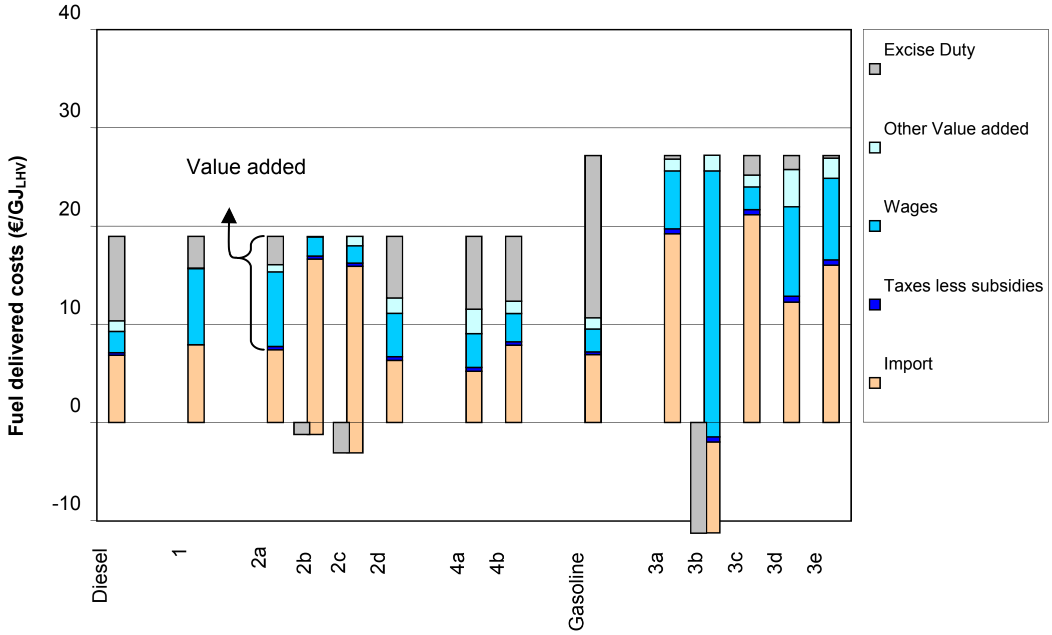

Figure 4-4: The breakdown of the GJ price of diesel, biodiesel, gasoline and bio-ethanol into import and value added (taxes less subsidies, wages, excise duty and other value added, but excluding VAT). A same delivered price per GJ is assumed. The excise duty on gasoline is 0.536 €/l, on diesel 0.305 €/l.

The total value added to the Belgium economy follows from addition of all items except import. This is shown in the figure, for the case of biodiesel from Belgium rapeseed. The value added for the options biodiesel from rapeseed and from waste vegetable oil are comparable to the value added of the fossil diesel they replace. This is under the condition that the rapeseed is produced on set-aside land, otherwise, additional rapeseed import would be needed, and this effect should be accounted for in the analysis.

The import of ethanol from Brazil to Belgium is also included in the figure. The value added and wages that can be earned are comparable to when bioethanol is produced from half Belgium and half Polish wheat. We have assumed that the import tax does not flow to Belgium but to Europe (and have allocated it to the import part). If a part of the import tax is rebated to Belgium this would add to the value added for Belgium and import of bioethanol from Brazil would clearly be more attractive than import of rapeseed from Poland and processing in Belgium.

Job creation

While direct job creation can be derived from the resulting wages, it must be realised that this is at the cost of lower tax income. To make a fair comparison, it should be analysed how much these extra jobs cost and how this compares to e.g. unemployment allowances.

5 LIFE CYCLE ANALYSIS

5.1 Introduction

During the lifecycle of bio-fuels and bio-energy, there is consumption of energy and emission of greenhouse gasses during biomass feedstock production, transport of the raw material and products, conversion of the feedstock into a bio-fuel, and use of the fuel in cars.

There are also many other interferences along the supply chain, such as other emissions, consumption of non-energy abiotic material (e.g. ore), and land use. These can have various impacts on environmental themes, such as a greenhouse effect, acidification, eutrophication, toxication, ozone layer depletion and photochemical smog. Also fossil energy carriers and other abiotic resources are consumed. By means of lifecycle assessment (LCA), all these effects can be studied. Whereas there exist a large amount of well-to-wheel energy and greenhouse gas balances of bio-fuels [Van den Broek et al. 2003], the number of full LCA studies on bio-fuels on these impacts is still limited.

Within the Libiofuels project, many bio-fuels supply chains have been chosen that should be analysed on their environmental performance. In the Netherlands, Ecofys has assessed the lifecycle of ethanol from wheat and of bio-diesel from rapeseed. The models and assumptions can partly be used for evaluating these chains in a Belgium context. Other chains, for which less detailed data is available will be analysed on their energy and greenhouse gas balance only (see Table 5-1).

5.2 Method - Energy and greenhouse gas balance

As stated in Chapter 3, each supply chain for liquid bio-fuels is divided into five sections (Figure 5-1). For supply chains to electricity and / or heat only the first three sections are relevant. The energy demand and greenhouse gas emissions are calculated per section, and expressed per km driven by the end-user in the case of liquid bio-fuels, or per kWh in case of electricity and heat.

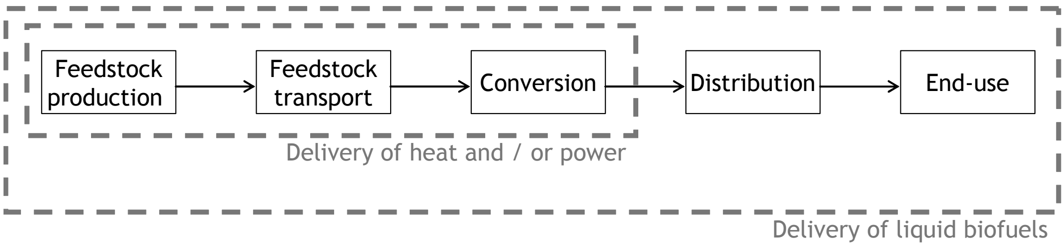

Figure 5-1: The supply chains for liquid bio-fuels or other bio-energy.

Greenhouse gas emissions

Only direct energy use and direct greenhouse gas emissions are taken into account. This means that indirect emissions, e.g. in the production of machinery is assumed negligible. However, an exemption is made for the production of fertiliser. Fertilizer production is energy intensive, and during production of nitric acid N_2O is emitted, which is a strong greenhouse gas[1]. In agriculture, N_2O is emitted from the field as a result of nitrogen fertiliser application. The emission is a function of the applied amount of fertiliser, the nitrogen uptake by the plant, the fate of crop residues, and ambient conditions.

Table 5-1. Chains researched.

	Feedstock	Origin	Conversion	End product	Research
1	Rapeseed	Belgium	Cold pressing	PPO	GHG balance
2a	Rapeseed	Belgium	Chemical extraction + esterification	Biodiesel	LCA
2b	Rapeseed	Imported	Chemical extraction + esterification	Biodiesel	GHG balance
2c	Rapeseed oil	Imported	Esterification	Biodiesel	GHG balance
2d	WVO		Pre-treatment + esterification	Biodiesel	GHG balance
3a	Wheat	Belgium + imported	Hydrolysis - fermentation - distillation	Bioethanol	LCA
3b	Sugar beet	Belgium	Hydrolysis - fermentation - distillation	Bioethanol	LCA
3c	Sugar cane	Imported		Bioethanol	GHG balance
3d	Wood	Belgium	Bacterial digestion - distillation	Bioethanol	GHG balance
3e	Wood	Imported	Bacterial digestion - distillation	Bioethanol	GHG balance
4a	Wood	Belgium	Gasification - upgrading - FT	BTL	GHG balance
4b	Wood	Imported	Gasification - upgrading - FT	BTL	GHG balance
5a	Wood	Belgium	Heat boiler	Heat	GHG balance
5b	Wood	Imported	Heat boiler	Heat	GHG balance
6a	Wood	Belgium	ORC	CHP	GHG balance
6b	Wood	Imported	ORC	CHP	GHG balance
7a	Wood	Belgium	Gasification	CHP	GHG balance
7b	Wood	Imported	Gasification	CHP	GHG balance
8a	Wood	Belgium	Co-combustion	Electricity	GHG balance
8b	Wood	Imported	Co-combustion	Electricity	GHG balance
9a	Wood	Belgium	Combustion in steam power plant	Electricity	GHG balance
9b	Wood	Imported	Combustion in steam power plant	Electricity	GHG balance

1) The ratio between import and domestic production for concepts 3a is 50%.

In most sections of the supply chain, greenhouse gas emissions consist mainly of CO_2, directly related to energy use through a fuel specific emission factor.

Annex C contains all details about CO_2 and N_2O emissions.

Economic allocation

At some stages in the fuel supply chain, there may be multiple products that all have an economic value. E.g. in the production of bio-diesel, rapeseed cake and glycerine are co-produced. When examining the energy balance and greenhouse gas emissions of the complete chain to bio-diesel, the co-products should be taken into account as benefits. This can be done by system enlargement or by allocation.

1 Climate change is expressed as global warming potential (GWP) or kg CO_2 equivalent. Most relevant emissions in this respect are CO_2 itself, CH_4 and N_2O, for which we applied 1, 23 and 296 CO_2 -eq respectively. Elsayed et al. [2003] used the same values (except that they categorised the 500 years horizon as 200 years). In other studies, sometimes a GWP of 21 for CH_4 and of 310 for N_2O are used for the 100-year horizon, these values stem from the 1995 IPCC Second Assessment Report.

In system enlargement, one assumes that the production of bio-diesel partly reduces feed-crop production for animals. The energy use and emissions avoided by this replacement can be subtracted from the examined bio-fuel chain. A problem with system enlargement is the risk of endlessly expanding the examined system and thus introducing more uncertainties[1].

In allocation, one argues that the energy use and emission burden of the chain can be divided over multiple products. The division factor can be based on mass, energy content, or economic value. The latter is used in the present Chapter, whereas energy allocation is used in the SPA in Chapter 6. When the economic value of (co)products changes drastically, this would change the results.

Data

Much of the data used for the present analysis was previously collected in the Dutch LCA [Hamelinck, 2005]. For some processes, data were supplied as collected for the perturbation analysis in Chapter 6. Belgium specific data has been used for the agricultural section of the supply chain. The detailed data applied for this chapter can be found in the different Annexes.

5.3 Method - lifecycle assessment

Lifecycle assessment planning and structure

Lifecycle assessments are subject to an organised structure:

1. Goal and scope
2. Inventory
3. Impact assessment
4. Interpretation

Goal and scope

In this phase the initial choices are made that fix the work plan for the complete LCA. The goal depends on the exact research question, the target group and the application. The scope considers the time frame, the geographical locations and the state of the technology. In this phase the product systems (fuel chains) to be compared are defined in a broad and generic sense.

Inventory

The inventory defines the product systems in more detail, by focussing on sub processes, limiting the process trees, gathering data, and calculating allocation or defining system extension in case of multi-product processes.

In the present LCA, Ecofys designed the process trees and delivered input for the subprocesses. Both stakeholders and experts assisted in filling-in data for e.g. the feedstock production, the conversion and the end-use processes. Use was made of Ecoinvent databases for the majority of subprocesses, which were expected to have less impact on the overall results.

1 The perturbation analysis (SPA) in Chapter 6 is a form of system expansion. SPA aims at looking only into a well defined system, and does not look at the world. This has the advantage that the effects on the Belgian system of introducing bio-fuels become visible. The limited perturbation analysis will not show positive or negative impacts in other countries, and may decouple the emission and uptake of CO_2 in biofuels chains.

The product of this phase is the input and output to the environment per subprocess and subproduct, in terms of emissions and energy and material use. These inputs and outputs are calculated for the complete process tree. This yields a table with inputs and outputs expressed in the functional unit (i.e. per km).

Impact assessment

In the impact assessment the effects of the emissions and inputs to the chain are multiplied by their respective impacts on different environmental categories. These impacts are expressed in equivalent units. For example, CO_2, N_2O and CH_4 have a respective impact on climate change of 1, 296 and 23 kg CO_2-equivalent.

The inventory step yields results for the biofuel and fossil fuel chain in comparative units on a comparative basis (per km). A normalisation step compares the contribution of this km fuel use to the total Dutch national environmental impacts.

Interpretation

In this step the results are evaluated and analysed, and conclusions can be drawn. The analysis encompasses the relative contribution of process steps to the total. For this reason, the total chain will be split into smaller parts.

A sensitivity analysis is done on several parameters to show the impact of changing some prominent parameters on the performance of the biofuel chains.

Use of by-products and allocation

When a process has multiple outputs, the impacts have to be allocated to these outputs. In order to avoid multiple products in the eventual comparison[1], co-products can be compensated within the system, or brought outside the system. The former is called system extension, the latter allocation.

In system extension, it is assumed that the co-product replaces a product elsewhere. This replaced product also resulted from a production process, which is now avoided. By subtracting this avoided production process from the bio-fuels chain (or adding it to the fossil fuel chain) one can make both chains comparable. However, if the discussed replaced product was not the only product of that process, one creates a new problem. Namely, one should also account for the unwanted avoidance of the second co-product. This could lead to a range of substitutions. Each of these substitutions introduces new assumptions, chain definitions and allocations. On the other hand, it may be impossible to find a substitution process[2]. While the ISO standard prefers to use system extension, it is not always possible.

Allocation is the other possible solution. Here, both products are valued, and the environmental burden of the upstream processes is allocated partially to the main output and partially to the co-product. There are different grades in allocation. As advised by the LCA methodology expert, economic allocation is used, which accounts for the economic value of products. The product share that represents x% of the economic output (amount times market price) also bears x% of the emissions. In some occasions, where market values are not

[1] Otherwise, results would be expressed very unnatural, e.g. per "km driven + 7 g glycerin produced".

[2] Envision a process that produces electricity from chicken litter. One of the co-products of the chicken litter is an egg. It is nearly impossible to produce an alternative egg without employing a bird that co-produces litter.

available, mass, or another physical parameter that is sufficiently representative for the economic value, may be used as an allocation basis.

Although in principle both allocation and system enlargement may be applied, the results could be very different. In allocation all impact burden is split over two products. This means that *all* impacts of the main product chain will decrease with the same fraction. When system enlargement is applied, this will typically affect some impacts more than others. For example, if CO_2 is a valuable by-product, system enlargement with replacing CO_2 production from natural gas would typically have more effects on fossil energy carrier depletion and climate change.

The method used for the LCA in this study is economic allocation. The perturbation method (see Chapter 6) applies both system extension and energetic allocation for the first level by-products.

Data sources

For the present lifecycle analysis, the data from the Dutch study "A participative LCA on bio-fuels" [Hamelinck et al., 2005] has been used where applicable. Some of the data from the SPA analysis (Chapter 6 and Annexes) has also been used. All data used can be found in the different Annexes.

Normalisation

Normalisation increases the understanding of the importance of each impact category. It is a more or less objective step to illustrate which impacts are relatively important. Normalisation is done against the total impacts in Western Europe in each impact category, see Annex F.

5.4 Results - greenhouse gas balance on liquid biofuels

In Figure 5-2, the results for the greenhouse gas balance are shown. The results for chain 2a, 3a and 3b, as well as the results for the fossil diesel and fossil gasoline chain stem from the lifecycle assessment discussed in Section 5.6. The results for the other chains are calculated as discussed above in Section 5.2.

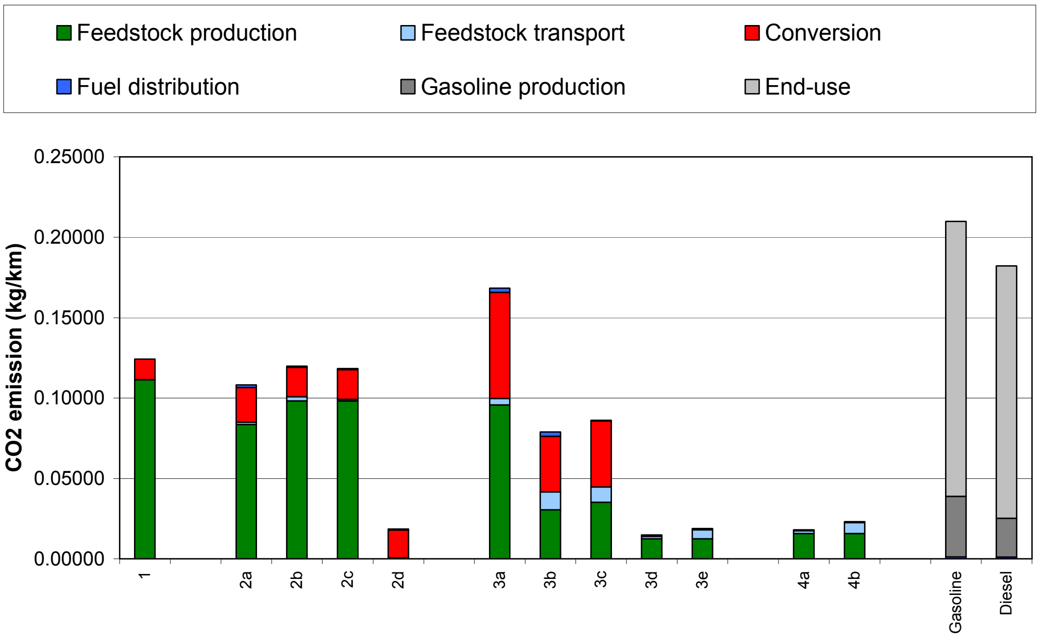

Figure 5-2: CO_2 emission from the different biofuel chains, compared with fossil diesel and fossil gasoline. The results for chain 2a, 3a and 3b, as well as the results for the fossil diesel and fossil gasoline chain stem from the lifecycle assessment discussed in Section 5.6.

All analysed biofuel chains lead to a net reduction of greenhouse gas emissions. For rapeseed oil and rapeseed biodiesel, the reduction is about 40%, the majority of the greenhouse gas emissions is in agriculture, more specific in N_2O from the production and application of fertiliser.

In chain 2d, which analyses biodiesel from recoverable vegetable oil, there are no emissions from feedstock production, since the feedstock is considered a waste product, and every emission that occurred in the chain up to the oil, is allocated to other applications (such as the frying of a product).

The bioethanol chains show varied results. Bioethanol from wheat (chain 3a) has a limited greenhouse gas emission reduction. The emission in agriculture is as high as in the production of biodiesel, but on top of this there are extra emissions from the conversion process. The major part of these emissions stem from energy use (heat) for distillation. This energy could also be supplied from a sustainable source. That would greatly improve the greenhouse gas balance. Ethanol from sugar beet (chain 3b) and from sugar cane (chain 3c) profit from higher yields per hectare and (relatively) lower fertiliser input. But the greatest greenhouse gas emission reduction could be realised with the use of ethanol from woody biomass (chains 3d and 3e).

Finally, Fischer-Tropsch diesel (chains 4a and 4b) shows a reduction of about 90% over the use of fossil diesel. The small emission that takes place, almost entirely stems from feedstock production. The conversion from wood to diesel is almost energy neutral, because of the co-production of heat and electricity within the process.

5.5 Results - greenhouse gas balance on heat and power from biomass

Chains 5 through 9 produce heat and / or power. Especially the chains that deliver both heat and power cannot easily be compared with fossil alternatives, since the same product mix would have to be delivered. Also, there are many technology options to produce heat and / or power from fossil fuels. And, finally, the fossil feedstock mix has not been defined; in Belgium reality the electricity is produced for a large part from nuclear energy.

For this analysis we have assumed that the efficiencies for the fossil energy chains are comparable with those chosen for the bio-energy chains. Generally, using natural gas for the production of heat and /or power will be more efficient than using solid biomass, but the efficiency assumed for bio-energy production is already quite high. Also, it would not be fair to allow biomass having a higher efficiency (in some chains) and at the same time to keep the efficiency of coal to electricity low. Finally, the energy gain or loss that we want to study is expected to reside in the supply chain of biomass.

For chains 5 through 7, which concern the production of heat, and the co-production of heat and power, we have assumed that the alternative is produced from natural gas. For chains 8 and 9, which concern the production of electricity, we have assumed that the alternative is produced from a mix of coal (30%) and natural gas (70%).

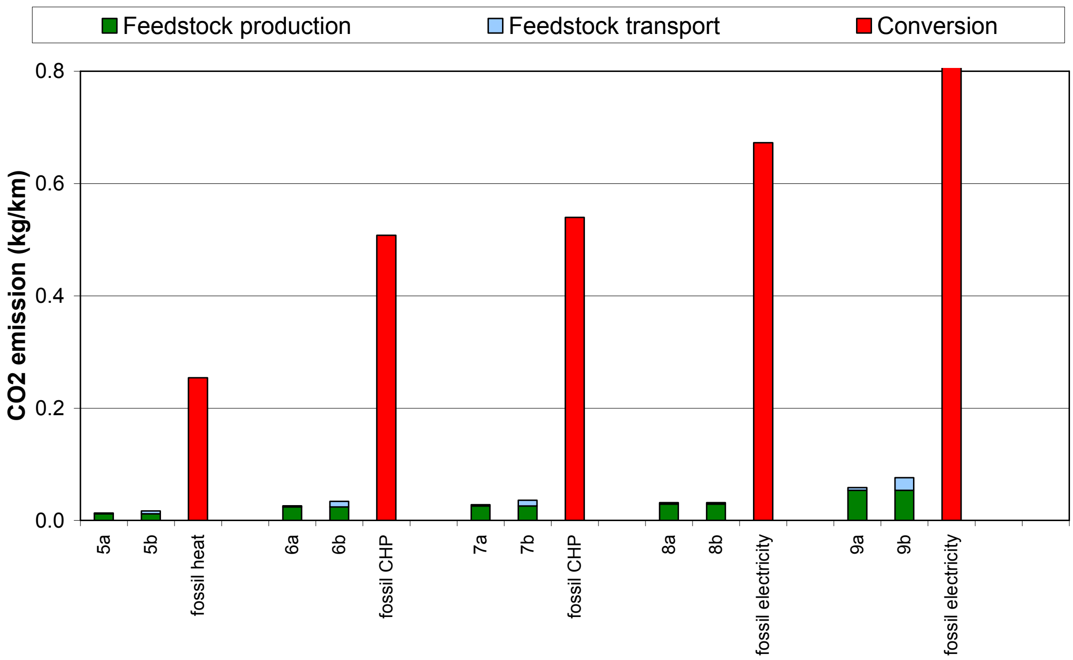

Figure 5-3: CO_2 emission from the different biomass to heat and / or power chains, compared with fossil alternatives. For the fossil chains the same energetic efficiency is assumed as for the bioenergy chains.

The results are presented in Figure 5-3. There is a large reduction in greenhouse gas emissions when replacing fossil fuels (coal and gas) with biomass to generate heat and/or power. The energy related CO_2 emissions from supplying the biomass are small in comparison with the end-use CO_2 emissions from fossil fuels. Even if better efficiencies were assumed for the fossil alternatives, there would remain a large greenhouse gas advantage for biomass.

5.6 Results - lifecycle assessment

A life-cycle assessment has been performed for the following chains:

- Bio-diesel from Belgium rapeseed (Chain 2a)
- Bio-ethanol from Belgium and imported wheat (chain 3a)
- Bio-ethanol Belgium and imported sugar beet (chain 3b)

Bio-diesel from rapeseed

The results for the comparison of driving on bio-diesel with driving on fossil diesel are given in Figure 5-4. From left to right, 14 impact categories are presented. Within each category the bio-fuel chain is being compared with the fossil fuel chain. The results within each impact are normalised to 100% for the chain with the strongest impact. The most value should be given to the four groups of bars on the left: energy carrier depletion, climate change, acidification and eutrophication. These categories are often put forward in discussions on bio-fuels. The search for LCA data was also driven much by the desire to give insights in these categories.

The results are aggregated to the five distinguished steps of Figure 5-1: feedstock production, feedstock transport, conversion, fuel distribution, and end-use.

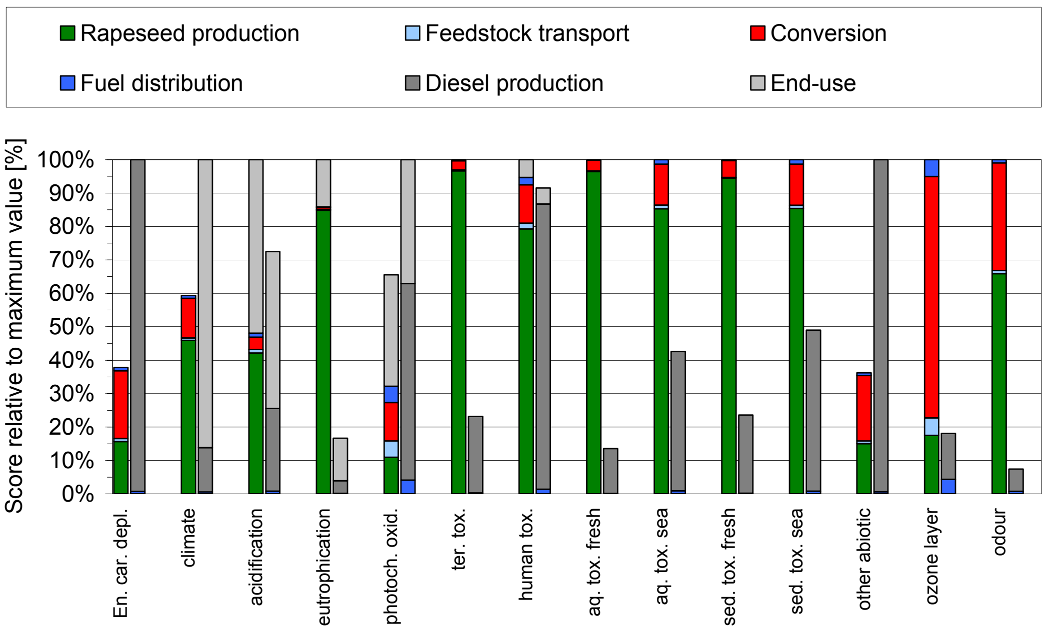

Figure 5-4: Comparison of the lifecycle impacts of driving on biodiesel with driving on fossil diesel. In diesel production all impacts are included up to the exit of the refinery.

To drive on bio-diesel still requires inputs of fossil energy in the various process steps. Per kilometre driven, the bio-diesel chain consumes about 38% of the amount fossil energy that is required to drive on fossil diesel. Half of this is in the production of feedstock and the other half in the conversion of rapeseed to bio-diesel. Transport and distribution contribute only marginally. In the production step, 37% of the energy exists of natural gas, entirely in the production of fertiliser. About 50% of the fossil energy is oil, used partly (19%) on the field to drive the tractor, and further (31%) for the production of fertiliser (16% for nitrogen fertiliser, 10% for phosphate, and 5% for potash). The remainder of energy in agriculture consists of coal, indirectly required for electricity with the production of fertiliser. The fossil energy used in the conversion step is made-up from energy required for pressing (31%), for the transesterification (26%), and for natural gas required to produce the methanol for transesterification (38%).

The total global warming potential of the bio-diesel chain is 110 g CO_2 eq./km, compared with 180 g CO_2 eq./km for the fossil fuel chain. This means that in *this* comparison the bio-diesel chain performs some 40% better than its fossil equivalent. Note that other literature sources may report different values for diesel baseline vehicles (e.g. range from 170 to 200 g/km [Van den Broek et al. 2003]) depending on timeframe, location, technological assumptions and applied research method.

Energy use causes CO_2 emissions and is therefore also responsible for a large part of the climate change category. However, there are also greenhouse gas emissions that do not relate with energy use. Therefore the contribution of the various chain steps to this category is not the same as for energy carrier depletion. The largest part of greenhouse gas emissions takes place in agriculture. 28% of this is in the form of CO_2 (7% by tractor use, 21% because of fertiliser production). 71% of the climate emissions in the agricultural step consist of N_2O. This is emitted partly by the production of sulphuric acid for nitrogen fertiliser production (25%), the rest stems from emissions from the field as a result of the application of fertiliser (46%). N_2O emissions from fertiliser production may be reduced quite easily in the future (See Annex C.10).

The acidification of the environment increases, when driving on bio-diesel in comparison to driving on fossil diesel. The graph shows that the acid emissions from end-use are only marginally larger. The larger overall impact is caused by the production of rapeseed. In the agricultural step, 48% of the acidic emissions consist of ammonia (13% in the production of nitrogen fertiliser, 35% in the application), 25% is NO_x (11% through tractor use, 7% through production of fertiliser, and the rest through direct emission from the field) and 27% is SO_x (almost all in the production of fertiliser).

Eutrophication is caused for a small part by the same emissions, and further especially by nitrate and phosphate leaching from the field (73% respectively 16% of the feedstock production section).

Toxicity is presented in six categories (terrestrial, human, aquatic toxicity for fresh water and for sea water, and sediment toxicity for fresh water and sea water). The uncertainties in toxicity impacts do not fully justify the presentation in six categories. The results can be very sensitive to a few toxic components. If that component, however small, is missed in one of the chains, the results can become distorted. Also, the uncertainty for toxicity impacts from the bio-ethanol chain is larger than for the first four categories, since there was less focus on this impact during the stakeholder interactions. Finally, there is still considerable discussion within the LCA community on the impact assessment indicators in this category (as opposed to other categories).

Terrestrial and human toxicity almost entirely stem from pesticide use in agriculture and further from small emissions of heavy metals.

Other abiotic depletion considers the use of materials from the earth, apart from fossil fuels: mineral ores, phosphates, etc. In the ethanol chain, conversion contributes the larger share, apparently as a result of natural gas consumption (the actual materials depleted are unknown).

The delivery of fossil energy gives a higher impact. Again, the uncertainties in this category are large, especially because of limited stakeholder involvement.

Ozone layer depletion in the conversion step mainly resides in the emission of halon-1301 (57%) from electricity production in Europe from coal, oil and gas, and in the emission of HCFC-22 (9%) that originates from the transport of natural gas.

The odour from the ethanol chain is for the major part (53%) caused by hydrogen sulphide emissions from the production of a small amount of natural gas in Russia. This shows that a small, single odour emitter can distort the entire picture. This happens especially in impact categories that are less well-known or perceived less important. Also, odour emissions are very local.

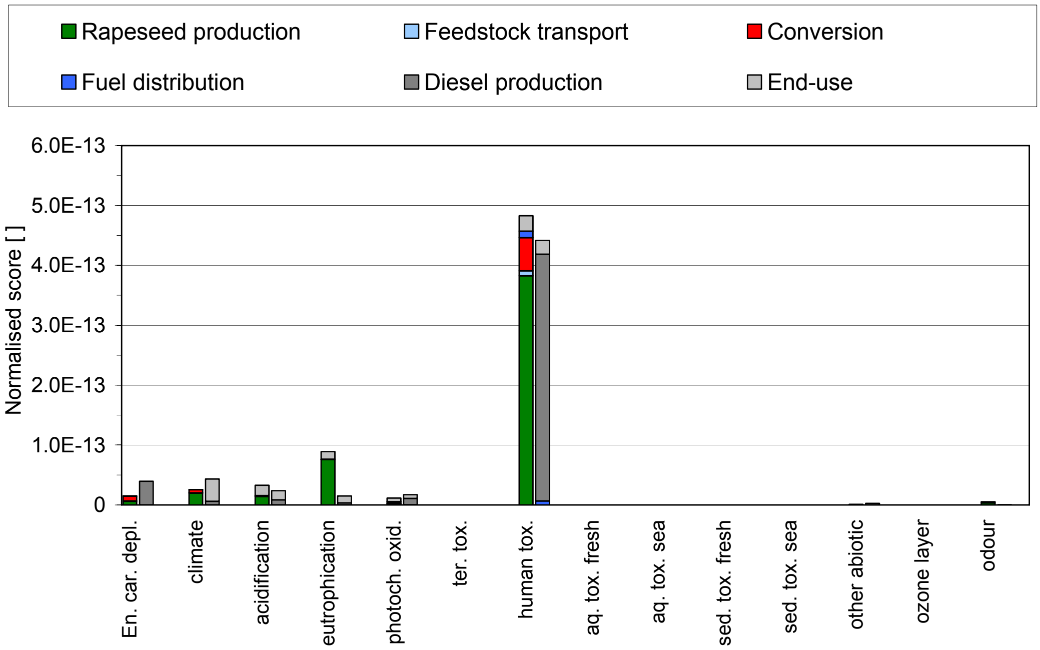

Figure 5-5: Impacts of driving on biodiesel and fossil diesel, normalised against Western European territory impacts (1995).

The results have been normalised against emissions in Western European territory impacts (see Annex F) to show the relative importance of various categories (see Figure 5-5). This means that the impact assessment results are divided by the total environmental impact of the processes in Western European economy. The scale of the normalised score is very small, (10^{-13}) since one km driving on either fuel is compared with the total Western European score on each impact. One can conclude from this graph that in discussing replacement of diesel with bio-diesel, the subjects energy carrier depletion, climate change and acidification are less important issues than e.g. eutrophication. However, this was the other way round in the Dutch LCA. However, the human toxicity category seems the most important. It must be stressed that this category incorporates large uncertainties in input data methodology. In order to draw conclusions on (dis)advantages of bio-diesel in this category, it would be necessary to examine this category in more detail.

Bioethanol from wheat

The results for bio-ethanol compared to gasoline are shown in Figure 5-6. There is fossil energy use in feedstock production, but the largest contributor is the conversion step (the ethanol factory). In feedstock production, the energy use distributed over machinery use (diesel) and fertiliser production. In the ethanol factory, the largest energy use resides in distillation, which requires relatively low temperature heat, which in the baseline comparison is assumed delivered from natural gas. In the Dutch LCA, it has been shown that this part of the energy use can be drastically reduced if the heat is supplied from a renewable source, such as the straw from the field (When the heat is delivered from combusting straw (via CHP), the reduction can be 65%).

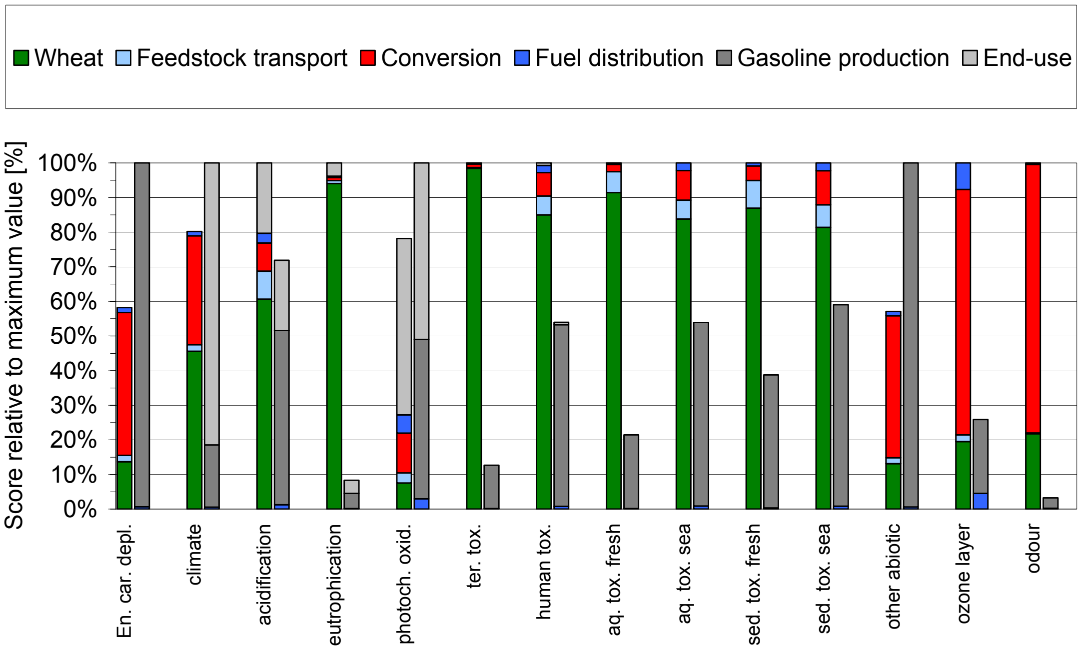

Figure 5-6: Comparison of the lifecycle impacts of driving on bioethanol from wheat with driving on fossil gasoline. In gasoline production all impacts are included up to the exit of the refinery.

The total global warming potential of the bio-ethanol chain is 170 g CO_2 eq./km, compared with 210 g CO_2 eq./km for the fossil fuel chain. This means that in this baseline comparison the bio-ethanol chain performs some 20% better than its fossil equivalent.

Part of the climate impact can be related to energy use. This is the case in the conversion facility where natural gas is combusted to generate heat, and CO_2 is emitted. In agriculture, only 23% of the emissions are actual CO_2 emissions that can be related with energy use (machinery and fertiliser production). The largest part again stems from N_2O emissions (76%). These N_2O emissions are caused by fertiliser production (27%) and by application of the fertiliser on the field (49%).

The bio-ethanol chain performs worse than gasoline on the items of acidification and eutrophication. This is mainly caused by emissions from agriculture. Acidification through agriculture is caused by air emissions of ammonia (55%), NO_x (20%) and SO_x (24%). The ammonia emission is again largely related with fertiliser production and use. The NO_x emission stems partially from fertiliser production and partially from tractor use. Eutrophication from agricultural actions is caused by nitrates (74%) phosphates (16%). The end-use emissions responsible for acidification and eutrophication are assumed to be the same for the bio-ethanol and gasoline chain.

Photochemical oxidation (smog) originates mostly from the end-use, which is the same for the ethanol and gasoline chain, because the end-use emissions are assumed not to change when replacing gasoline with ethanol (see Annex E). In the ethanol chain, there are smaller contributions from feedstock transport and conversion. In the fossil chain the delivery of gasoline contributes to about half of the total smog impact. This mainly resides in the crude oil production.

Also the results for this comparison have been normalised against emissions in the Western European territory to show the relative importance of various categories (see Figure 5- 7).

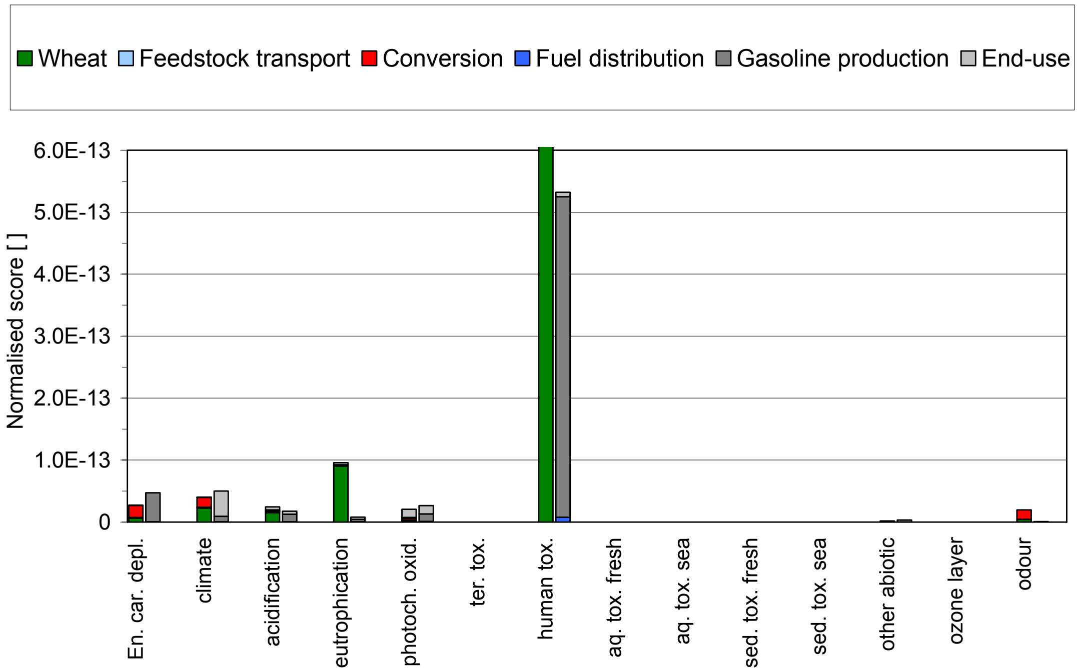

Figure 5-7: Impacts of driving on bioethanol from wheat and fossil gasoline, normalised against Western European territory impacts (1995).

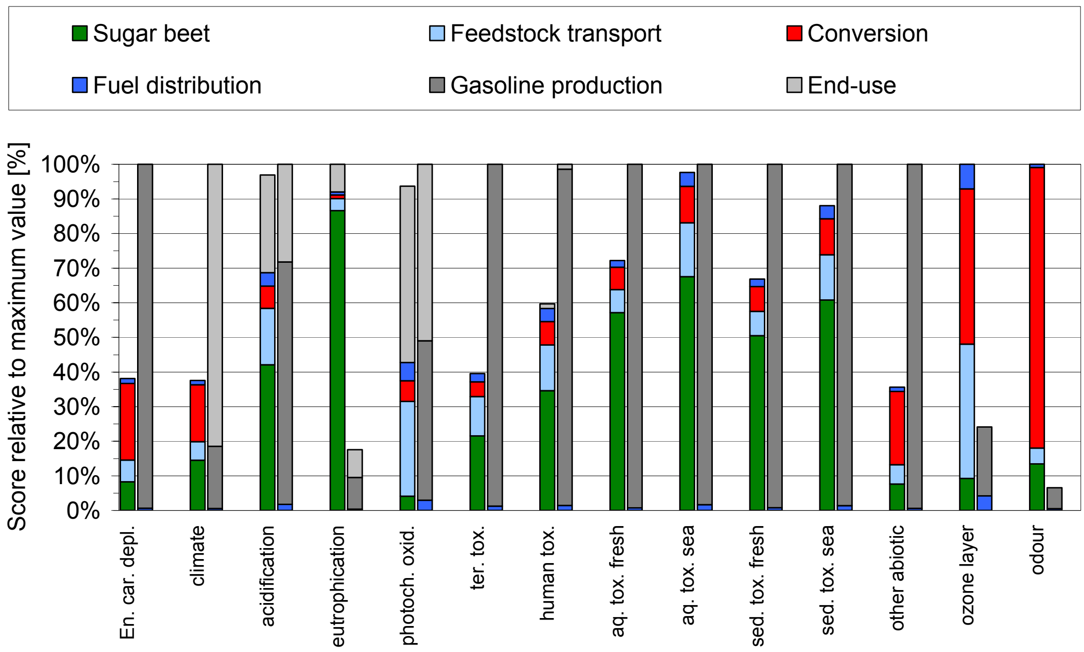

Figure 5-8: Comparison of the lifecycle impacts of driving on bio-ethanol from sugar beet with driving on fossil gasoline. In gasoline production all impacts are included up to the exit of the refinery.

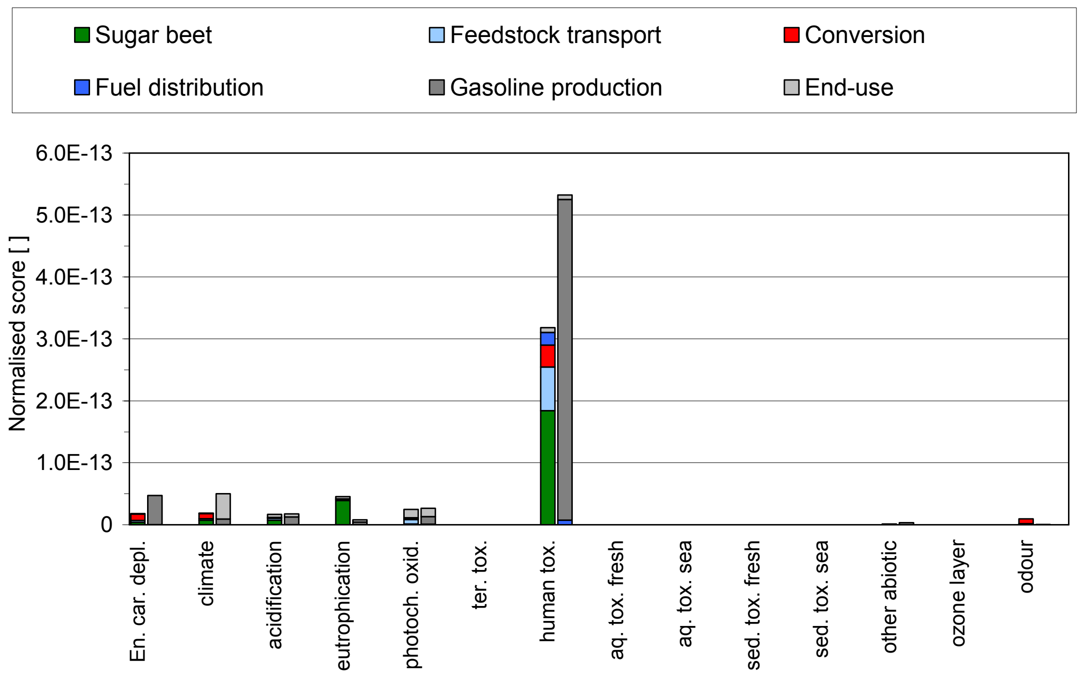

Figure 5-9: Impacts of driving on bio-ethanol from sugar beet and fossil gasoline, normalised against Western European territory impacts (1995).

Bio-ethanol from sugar beet

To drive on bio-ethanol from sugar beet requires 60% less fossil energy input compared to driving on gasoline[1], see Figure 5-8. This is better than the production from wheat. The gain resides in both a lower energy use in the production, caused by the higher yields per hectare, and a reduction in energy required in the conversion process.

5.7 Conclusions

First, it has to be stressed that the results from the present greenhouse gas balance and lifecycle assessment only hold for the cases and choices presented. If chains would be designed differently, the results would be different. E.g. the production of ethanol from agricultural residues can be more energy efficient and with less climate impact.

All analysed bio-fuel chains lead to a net reduction of fossil energy use and greenhouse gas emissions. On energy basis, the bio-diesel chain performs about 60% better than the diesel chain. There are equally large fossil energy uses in feedstock production and the conversion step. In the production of rapeseed feedstock, the larger part (80%) is in fertiliser production, and the remainder mainly in tractor use. In the conversion to bio-diesel, the largest consumer of fossil fuel is the production of methanol from natural gas (38%). Another 19% energy share resides in heat for the bio-diesel plant. Smaller amounts of gas and fuel oil are used for drying the raw rapeseed, and heat in the oil pressing plant.

When driving a car on bio-ethanol instead of gasoline, 40 - 60% less fossil energy is used. There is a small fossil energy requirement in the agricultural step (fertiliser production and tractor use). The largest demand for fossil energy is in the conversion of wheat to ethanol. This is especially caused by the heat required for distillation. Other separation technologies may reduce this heat demand. On the other hand, the energy and climate impact can also be greatly improved by supplying the heat through renewable energy sources, as was shown in the Dutch study. A closer look at the integration of heat, power, and bio-fuels within a bio-ethanol factory could further improve its performance.

Compared to fossil fuels, bio-fuels have a reduced impact on climate change. Bio-diesel performed about 50% better than diesel, bio-ethanol about 20 - 60% better than gasoline. Fertiliser use had a large impact on climate change in all bio-fuels' chains. This was caused by emission of N_2O during both the production and use of N-fertiliser. The N_2O emissions during fertiliser production can be reduced to almost zero by relatively easy and cost-effective technological measures. These technologies are expected to be applied when legislative or economic driving forces are introduced, such as when N_2O would be included in the European Union Greenhouse Gas Emission Trading Scheme ETS. This is likely to happen on foreseeable terms. In the analysed chain, the CO_2 emission reduction in the bio-ethanol chain is limited. It can be greatly increased by improving the conversion facility.

For rapeseed oil and rapeseed bio-diesel, the emission reduction is about 40%, the majority of the greenhouse gas emissions is in agriculture, more specific in N_2O from the production and application of fertiliser. If bio-diesel is produced from recoverable vegetable oil, there are no

[1] Initially the calculations showed only a 15 - 20% decrease in terms of energy carrier depletion and climate change. This was caused mainly by the agricultural step, which for 86% consisted of direct energy use by the tractor. It was assumed that the tractor consumed 1876 kg diesel/ha. According to the Dutch Kwin [] this would be much lower (124 kg). The latter value has been used for the present analysis.

emissions from feedstock production, which leads to a very favourable overall greenhouse gas balance.

The bio-ethanol chains show varied results. Bio-ethanol from wheat has a limited greenhouse gas emission reduction. The emission in agriculture is as high as in the production of bio-diesel, but on top of this there are extra emissions from the conversion process. The major part of these emissions stem from energy use (heat) for distillation. This energy could also be supplied from a sustainable source. That would greatly improve the greenhouse gas balance. Ethanol from sugar beet and from sugar cane profit from higher yields per hectare and (relatively) lower fertiliser input. But the greatest greenhouse gas emission reduction could be realised with the use of ethanol from woody biomass.

Finally, Fischer-Tropsch diesel shows a reduction of about 90% over the use of fossil diesel. The small emission that takes place, almost entirely stems from feedstock production. The conversion from wood to diesel is almost energy neutral, because of the co-production of heat and electricity within the process.

There is a large reduction in greenhouse gas emissions when replacing fossil fuels (coal and gas) with biomass to generate heat and / or power. The energy related CO_2 emissions from supplying the biomass are small in comparison with the end-use CO_2 emissions from fossil fuels. Even if better efficiencies were assumed for the fossil alternatives, there would remain a large greenhouse gas advantage for biomass.

The assessed bio-fuels chains perform worse in terms of acidification and eutrophication; this is caused by the agricultural emissions of ammonia, NO_x, SO_x, nitrates and phosphates. End-use emissions relevant for these impact categories are the same for bio-fuels and their fossil alternatives.

The results in other impact categories are subject to large uncertainties.

6 SYSTEM PERTURBATION ANALYSIS

6.1 Introduction

The System Perturbation Analysis or SPA discussed and applied in the present chapter yields information which to a certain extent overlaps with the LCA, but which also adds information focused on the considered system (in casu Belgium). The approach is quite different from LCA : SPA investigates the impact of replacing any resource by another resource in a given system, which in the present case is Belgium (Figure 6-1).

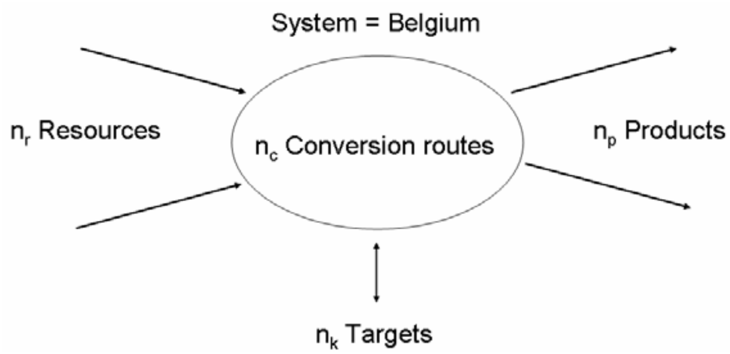

Figure 6-1: Considered 'system'

In the considered system, the 'resources' are transformed into 'products' through given 'conversion routes'. The conversions lead to impacts such as CO_2 emissions, costs, employment a.o., which are called 'targets'. The conversion routes also consume 'utilities' which are defined as all secondary resources needed in a chain. These are mainly gasoil, natural gas and electricity, and some others which are expressed in megajoules of extra primary energy (e.g. seeding, hexane, isobutylene,…). Water consumption is for the time being not considered in the analysis.

In Practice, the SPA aims at finding an answer to the question below.

For each unit of available alternative resource :

- what is the variation of a target
- when this alternative unit replaces a conventional resource,
- when applied to different end-uses,
- through different technologies

with following definitions :

- unit : kg, MJ prim, ha..
- alternative resource : rapeseed, land, …
- conventional resource : oil, gas, coal,..
- target : CO_2 , cost, employment, energy savings,..
- end-uses or products : transport, power, heat
- technologies : Fisher-Tropsch, Organic Rankine Cycle, ...

To find an answer, one single resource chosen by the user is perturbed with a specified amount (Figure 6-2). This automatically leads to a perturbation of at least one main product and maybe of several by-products. Since there is no consideration of any demand side management the amounts of products are considered to be constant. The perturbations on the products must therefore be compensated by perturbations on an least one other resource, which on his turn may induce other perturbations in the products, etc.. As an example, a hectare of set aside land can be converted into local wheat production for replacing gasoline by ethanol. The wheat production will automatically induce by-products such as straw and a residue used in animal feed, which on their turn will affect the production or import of straw and animal feed, etc…

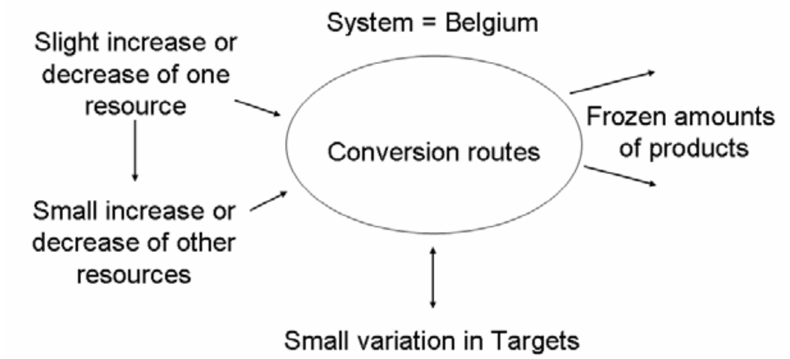

Figure 6-2: Perturbation of the system

The user somehow has to decide which resources are to be perturbed to keep the products in balance, in interaction with the analysis program, and it is advisable to include resources such as 'import' to ensure convergence of the analysis. When all perturbations are compensated, global perturbations on utilities and next on targets can easily be calculated.

When keeping the products constant, it is not always straightforward what type of compensation will take place. This is particularly true for products such as electricity, wheat and animal feed. Belgium is net importer of these products, which means that increasing their inside production should lead to a reduction in import or vice versa. The reality is more complex because of grid considerations in the case of electric power, and types of wheat and animal feed in the other cases. In a first approach a direct compensation by import will however be assumed for all products, whilst further inside modelling of such perturbations may be indicated.

It is important to note that replacement of e.g. locally produced wheat from food to non-food application automatically leads to extra import of wheat. The scenario's 'imported wheat' therefore do not care if the wheat for the ethanol really comes from local or foreign production.

6.2 Exact system boundaries

SPA requires an accurate definition of the system boundaries, which is illustrated in Figure 6-3. The system borders on land are the national frontiers, the borders on water are considered to be the sea harbours. The refineries are however considered as being outside of the system, because taking them inside the system would require the modelling of all conversion processes in such refineries, including what happens when perturbing their throughputs. For sake of simplicity crude oil is therefore not considered as a resource, and products such as gasoline, diesel a.o. which are now 'imported'. The program allows however to include or exclude the CO_2 emissions associated to the refinery operation, although it is not clear to what extent such CO_2 emissions are really perturbed.

SPA focuses on what happens inside and on the borders of the system, but the need of looking also into the 'outside world' appeared after producing the first results. This mainly happens by including the utilities consumed outside the boundaries, but without looking into how the outside world reacts on the perturbations. This extension allows to make more global evaluations on how efficient or CO_2 intensive the perturbations might be. These results can be compared with more classical energy and CO_2 balances as calculated in Chapter 5, and they allow for validation of the data and the calculation procedure. When looking only into the considered system, fossil fuel replacement and CO_2 emissions look often very different from the global values. The SPA allows to investigate where differences come from, and it therefore can be an important tool for decision making on the Belgian (or any other system) level.

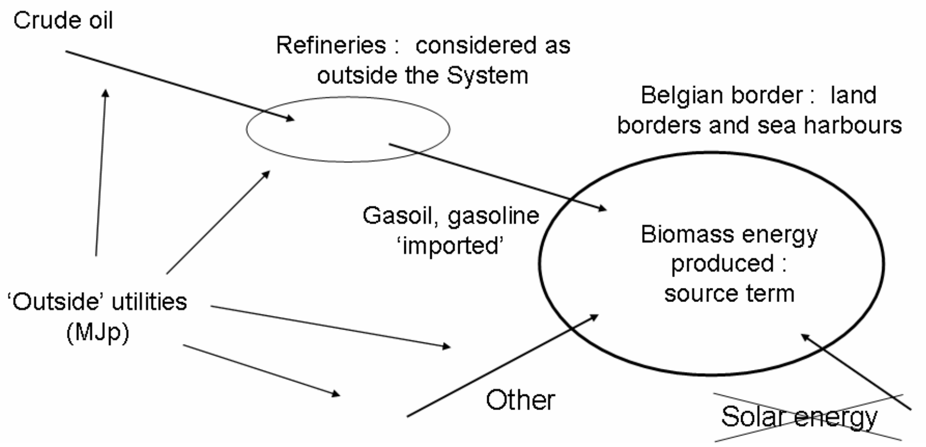

Figure 6-3: Boundaries of the system

The energy balances made in SPA should be taken literally : summations are made of 'first law' energy streams through the borders of the system, and energy efficiency is therefore different from the efficiency defined in Chapter 3. When making strict energy balances it is also needed to include the renewable resource terms, which for biomass is basically the solar radiation. For practical reasons this 'resource' is however not considered, and it is replaced by a 'source' term inside the system. This source term is calculated as the biomass yield per year, times its lower heating value (see e.g. Tables 2-4 and 3-1), and it is reported separately.

6.3 About energy, CO_2 and cost calculation

As far as energy and CO_2 are concerned, the system boundaries defined in section 6.2 are clear and unambiguous. Energies consumed and CO_2 emissions can easily be split into inside and outside values (except for the refineries). It is to be observed that no allocation of CO_2 is considered on ingoing and outgoing streams, which corresponds to the way our Kyoto commitments are defined. Imported electricity leads therefore to no CO_2 emission inside the system! The direct CO_2 emitted by the biomass inside the system is considered as neutral. Eventual carbon build-up or release in the soil has not been considered, although this may influence the real CO_2 savings by up to 10% for a period of some decades.

The SPA on itself requires no allocation model at all because global balances are made. When expanding the analysis to the 'outside world' an allocation model is however needed to quantify the utilities consumptions and CO_2 emissions of all imported products. Data for fossil fuels and electric power are taken from EU data (see annexes). Data for ethanol are taken from Brazil, whereas all other are obtained by extrapolation of the Belgian data through energetic allocation. Although this is not absolutely correct, it has the advantage of being obtained according to the same methodology.

The perturbation on 'costs' is a more complex matter. The monetary values of in- and outgoing streams can easily be calculated, but this is not sufficient to estimate the monetary impact of the perturbation. The added values of any activity perturbation inside the system (see Chapter 4) should be taken into consideration, which has not been done within the present contract time. Awaiting for this, any resource produced inside the system is assumed to 'cost' its market price, although part of this money is returning into the Belgian economy. Care must therefore be taken with the cost results as presented in the present analysis.

The cost figures exclude any kind of tax or subsidy, because this is internal recirculation inside the system. The sole exemption is the European tax on the Brazilian ethanol, since this tax is leaving the system towards the EU.

6.4 Considered resources, products and routes

The considered resources, products and routes are listed in Tables 6-1, 6-2 and 6-3. These partly correspond to the selected chains in the previous chapters, but more 'chains' are needed to perform the SPA. In addition some more variants are introduced to show the effect of e.g. different use of straw, the effect of making ETBE rather than ethanol and use of forest waste.

Table 6-1 : considered resources

Hectares for rapeseed, wheat, sugar beat and short rotation forestry
Hectares set aside land
Imports of rapeseed, rapeseed oil, wheat, ethanol, wood
Imports of gasoline, gasoil, natural gas, hard coal, heavy fuel oil
Imports of electricity
Imports of animal food, glycerine, isobutylene, straw, a.o.
Import of 'other' primary energy

Table 6-2 : considered products

Kilometres (gasoline, diesel)
Electric energy
Heat
Animal food (from wheat, sugar beet, rape seed)
Straw
Glycerine
MTBE/ETBE
Hectares*

* Hectares are considered as product to automatically ensure a constant usage of the available surface

Table 6-3 : alphabetic list of considered routes or chain combinations

Chain	Description	unit
	Animal food (DDGS) - imported	ton
	Animal food (rape seed) - imported	ton
	Animal food (sugar beat pulp) - imported	ton
	Coal for co-combustion	ton
	Electricity - imported	kWhe
	Ethanol for ETBE - imported	liter
3c	Ethanol for gasoline - imported	liter
	Gasoil for heat	liter
	Gasoil for transport	liter
	Gasoline for transport	liter
	Glycerine - imported	ton gl
	Heavy Fuel Oil	liter
	Methanol for MTBE - imported	liter
	Natural gas for heat	m3
1	Rapeseed for PPO	ha
2a	Rapeseed for RME	ha
2b	Rapeseed for RME - imported	ton rs
	Rapeseed for RME, glycerine burnt	ha
	Rapeseed for RME, glycerine burnt - imported	ton rs
2c	Rapeseed Oil for RME - imported	ton rsoil
	Set aside land	ha
	Straw - imported	ton
	Sugar beet for ETBE	ha
	Sugar beet for ETBE, pulp burnt	ha
3b	Sugar beet for EtOH	ha
	Sugar beet for EtOH, pulp burnt	ha
2d	Used vegetable oil for RME	ton uvo
	Wheat for ETBE - imported	ton wh
	Wheat for ETBE, straw burnt	ha
	Wheat for ETBE, straw for bedding	ha
	Wheat for ETBE, straw ploughed back	ha
	Wheat for ethanol - Imported	ton wh
	Wheat for ethanol, straw burnt	ha
3a	Wheat for ethanol, straw for bedding	ha
	Wheat for ethanol, straw ploughed back	ha
7a	Wood for CHP (FBG with PE)	ha
	Wood for CHP (FBG with PE) - forest waste	ha
7b	Wood for CHP (FBG with PE) - imported	ton wd
6a	Wood for CHP (ORC)	ha
	Wood for CHP (ORC) - forest waste	ha
6b	Wood for CHP (ORC) - imported	ton wd
8a	Wood for co-combustion	ha
	Wood for co-combustion - forest waste	ha
8b	Wood for co-combustion - imported	ton wd
	Wood for ETBE	ha
	Wood for ETBE - forest waste	ha
	Wood for ETBE - imported	ton wd
3d	Wood for ethanol	ha
	Wood for ethanol - forest waste	ton wd
3e	Wood for ethanol - imported	ton wd
4b	Wood for FT biodiesel - imported	ton wd
4a	Wood for FT biodiesel	ha
	Wood for FT biodiesel - forest waste	ha
5a	Wood for heat	ha
	Wood for heat - forest waste	ha
5b	Wood for heat - imported	ton wd
9a	Wood for small steam power plant	ha
	Wood for small steam power plant - forest waste	ha
9b	Wood for small steam power plant - imported	ton wd

In the ethanol cases, the ethanol can be used to replace directly kilometres from gasoline, by replacing or blending the gasoline mix. The ethanol can also be used to replace MTBE by ETBE. According to the physical properties of both products (see Annex A), the frozen amount of product may be taken as the sum of kg ETBE + kg MTBE. Hectares are also included as a product, by expressing that a hectare 'produces' a hectare. This is done to automatically ensure a constant amount of surface to be used in the system. Perturbing a surface resource will thus automatically induce the perturbation of another surface resource, such as replacing set aside land by land for wheat, or replace hectares sugar beat by rapeseed etc.

Table 6-3 contains the considered combinations of resource, conversion route and (main) product. Unless 'imported' is specified, the resource is produced locally and mostly consumes hectares of land. Combinations which have not been considered are the production of stationary power and/or heat from the liquid fuels. Although this happens in the reality, the analysis considers that the liquid fuels should be used for transport purposes. It is to be observed however that once a blended fuel is produced, the subsequent use does not matter too much. This can clearly be shown by SPA but is not done to keep the results overview comprehensive.

6.5 Results

The SPA analysis has been programmed in a MATLAB environment. The data for the analysis are reproduced by the program and are included in external Annex I, including the source for all the data. The scenario results are listed in external Annex J, where all details of the perturbation can be found. Table 6-4 shows a sample of Annex I, Table 6-5 is a sample of detailed SPA results and Table 6-6 shows a summary report sample as listed in Annex J.

Summary results of the SPA are shown in Figures 6-4 to 6-26. Owing to the quite different approach of SPA with respect to LCA results must be presented in a different way. Following definitions/criteria are used:

1) World energy efficiency as
   GJp world fossil energy saved / GJp world renewable energy produced
2) Energy efficiency Belgium as
   GJp fossil energy saved in Belgium / GJp world renewable energy produced
3) World CO_2 savings in kg CO_2eq/GJp world fossil energy saved
4) CO_2 savings in Belgium in kg CO_2eq/ GJp fossil energy saved in Belgium
5) Surface requirement in are/ GJp fossil energy saved in Belgium
6) Surface requirement in are/ kg CO_2eq saved in Belgium
7) Cost requirement in euro/ GJp fossil energy saved in Belgium
8) Cost requirement in euro/ kg CO_2eq saved in Belgium

Saved and produced energies are net values, after subtraction or addition of all utilities consumed and eventual renewable energy savings from by-products (e.g. in the case of wheat, eventual reduction of straw and DDGS imports are subtracted from the gross wheat production on the field). Criteria 1) and 2) thus tell us to what extent the net produced renewable energy effectively replaces fossil energy. Criteria 3) and 4) tell us the avoided CO_2 per unit of saved fossil energy. Criteria 5) and 6) tell us how the available surface area can best be used. Criterion 7) represents the cost generated if fully allocated to energy, whilst criterion 7) fully allocates the cost to CO_2. SPA mainly aims at the criteria 2) and 4) to 8).

Criteria 1) and 3) should be comparable to the results of Chapter 5. For criteria 2) and 4) to 6), no allocation model is used at all: the energy and CO_2 balances are real, provided the used data and import compensations correspond to reality. All saved fossil energies represent net savings, taking all direct and indirect effects into account. It is to be observed that a trading cost of 20 euro/ton CO_2 has already been taken into account in the analysis. It is also to be observed that in the case of wheat, the energy contained in the straw is included in the renewable energy production, which will be further detailed in Figure 6-12. The leaves from rapeseed and sugar beet are disregarded.

Figures 6-4 to 6-11 summarize the perturbations on primary energy, CO_2 and costs for a representative selection of perturbation scenarios. From Figure 6-4 it appears that all the scenario's show positive energy balances. The best scores are obtained from the wood to heat and / or power scenarios, with efficiencies even in excess of 100%. This is possible because of the CHP advantage (best case) and positive balances of production and transport energy requirements. Ethanol from import comes on the next place, the ethanol from Brazil being produced at rather low primary energy requirements and CO_2 emissions. RME from used vegetable oil comes next, followed by PPO from rapeseed which is a direct process whilst rape meal is fully recovered as animal feed. The five next scenarios show efficiencies around 60%, including wood for FT diesel and ethanol, wheat for ethanol and rapeseed for RME. The straw from the wheat production must be valorised either through combustion or as animal bedding, otherwise the efficiency significantly drops (see Figure 6-12). The sugar beat shows the lowest efficiency, which is due to the high energy requirements in distillation and pulp drying. Using the pulp for energy recovery improves the balance somewhat (not shown).

Figure 6-6 shows the corresponding CO_2 savings worldwide. All the scores are relatively high, keeping in mind that the fossil emissions range between 50 kg CO_2/GJ for natural gas, 70 for many liquid fuels and 100 for coal. The highest score is thus obtained for wood for co-combustion, mainly because of the high replacement efficiency combined with direct coal replacement. Wood for heat replaces gasoil, which has a lower specific emission. Wood for CHP has a lower score because the electricity produced is compensated by reduced import, with a lower emission coefficient. The slightly lower value for RME from imported rapeseed is due to extra transport, but also to the use of an allocation model based on (arbitrary?) energetic allocation.

Table 6-4 Sample of SPA energy, CO2 and cost calculation for one chain

```
=================================================
Wheat for ethanol, straw ploughed back
Internal code: 7
Resource expressed in: ha
Resource LHV: 23525.0 MJ/ton wh
Produces product  1: transport (gasoline)
Produces product  3: DDGS
Produces product 11: land
=================================================

Conversion factors:                            Production     Transport     Conversion     Distribution       End use
-----------------------------------------------------------------------------------------------------------------------------------
Product  1:                                     8.80e+000  *  9.90e-001  *   7.91e+003  *     9.99e-001  *  4.46e-001   km/ha
Product  3:                                     8.80e+000  *  9.90e-001  *   3.71e-001  *     1.00e+000  *  1.00e+000  ton/ha
Product 11:                                     1.00e+000  *  1.00e+000  *   1.00e+000  *     1.00e+000  *  1.00e+000   ha/ha

Utility consumptions:  Production              Production     Transport     Conversion     Distribution       End Use
-----------------------------------------------------------------------------------------------------------------------------------
Inside Belgium:
 Electricity:             332.915   MJ/ha           0.000        41.760         44.280           29.252          0.000 kWhe/ton wh
 Natural Gas:            6947.988   MJ/ha           0.000         0.000       4078.800            0.000          0.000   MJ/ton wh
 Diesel:                 4078.927   MJ/ha           0.000       796.266          0.000           69.915          0.000   MJ/ton wh
 Cheap diesel:           1280.275   MJ/ha           0.000         0.000          0.000            0.000          0.000   MJ/ton wh
 Coal:                    794.772   MJ/ha           0.000         0.000          0.000            0.000          0.000   MJ/ton wh
 Other Imported:         2497.500  MJp/ha           0.000         0.000         62.798            0.000          0.000  MJp/ton wh
Worldwide:
 Primary energy:        17733.636  MJp/ha           0.000      1043.465       4458.696          165.017          0.000  MJp/ton wh

CO2 & Costs:           Production              Production     Transport     Conversion      Distribution      End Use
-----------------------------------------------------------------------------------------------------------------------------------
CO2 inside Belgium:      3429.734   kg/ha           0.000        58.326        234.440            5.121          0.000   kg/ton wh
CO2 outside Belgium:      153.263   kg/ha           0.000        16.817         23.871            4.852          0.000   kg/ton wh
Costs:                      0.000  eur/ha         140.000         0.000        117.831           72.558          0.000  eur/ton wh
-----------------------------------------------------------------------------------------------------------------------------------
```

Table 6-5 Sample of SPA detailed perturbation results

```
==============================================================================================
Scenario  9
Perturbation by   1.0 ha of resource nr 26 Rapeseed for RME - local
==============================================================================================

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Perturbed Resource nr 2 Gasoil for transport (LHV =       35.9 MJ/liter)
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Resource decrease without utilities =   -1298.050 liter
Resource decrease with utilities    =   -1135.812 liter

                            Production    Transport   Conversion  Distribution      End use
--------------------------------------------------------------------------------------------------
World primary energy [MJp]:  -7447.524        0.000        0.000         0.000        0.000
CO2 inside [kg]:                 0.000        0.000        0.000         0.000    -3409.570
CO2 outside [kg]:             -660.968        0.000        0.000         0.000        0.000
Cost [euro]:                  -660.968        0.000        0.000         0.000      -68.191

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Perturbed Resource nr 26 Rapeseed for RME - local (LHV =        0.0 MJ/ha)
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Resource increase without utilities =       1.000 ha
Resource increase with utilities    =       1.000 ha

                            Production    Transport   Conversion  Distribution      End use
--------------------------------------------------------------------------------------------------
Electricity [MJ]:              338.010      150.336      537.230       201.506        0.000
Natural Gas [MJ]:             6883.314        0.000     4422.396         0.000        0.000
Diesel [MJ]:                  5556.972      901.588      425.106       299.473        0.000
Coal [MJ]):                    786.076        0.000        0.000         0.000        0.000
Other imported [MJp]:           27.480        0.000     3540.060         0.000        0.000
World primary energy [MJp]:  16954.255     1477.110    12988.116       925.450        0.000
CO2 inside [kg]:              3279.824       66.041      531.018        21.936        0.000
CO2 outside [kg]:              174.738       32.639      290.722        30.840        0.000
Cost [euro]:                   864.000        0.000      158.104       221.278        0.000




++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

Perturbed Resource nr 52 Animal food (rape seed) - imported (LHV = 16400.0 MJ/ton)

++

Resource decrease without utilities = -2.043 ton

Resource decrease with utilities = -2.043 ton

	Production	Transport	Conversion	Distribution	End use
World primary energy [MJp]:	-7945.029	-728.789	0.000	0.000	0.000
CO2 inside [kg]:	0.000	0.000	0.000	0.000	0.000
CO2 outside [kg]:	-1391.606	-54.942	0.000	0.000	0.000
Cost [euro]:	-224.782	0.000	0.000	0.000	0.000

++

Perturbed Resource nr 57 Glycerine - imported (LHV = 17000.0 MJ/ton gl)

++

Resource decrease without utilities = -0.128 ton gl

Resource decrease with utilities = -0.128 ton gl

	Production	Transport	Conversion	Distribution	End use
World primary energy [MJp]:	-943.675	-45.579	0.000	0.000	0.000
CO2 inside [kg]:	0.000	0.000	0.000	0.000	0.000
CO2 outside [kg]:	-274.770	-3.436	0.000	0.000	0.000
Cost [euro]:	-115.020	0.000	0.000	0.000	0.000

++

Perturbed Resource nr 59 Set aside land (LHV = 0.0 MJ/ha)

++

Resource decrease without utilities = -1.000 ha

Resource decrease with utilities = -1.000 ha

	Production	Transport	Conversion	Distribution	End use
Diesel [MJ]:	-1365.408	0.000	0.000	0.000	0.000
Other imported [MJp]:	-16.000	0.000	0.000	0.000	0.000
World primary energy [MJp]:	-1599.873	0.000	0.000	0.000	0.000
CO2 inside [kg]:	-727.536	0.000	0.000	0.000	0.000
CO2 outside [kg]:	-19.389	0.000	0.000	0.000	0.000
Cost [euro]:	0.000	0.000	0.000	0.000	0.000

Table 6-6 Sample of SPA summary perturbation results

```
==============================================================================================
Scenario  9
Perturbation by   1.0 ha of resource nr 26 Rapeseed for RME - local
Summary report
==============================================================================================
Perturbed Resource nr  2 by   -1135.81 liter Gasoil for transport
Perturbed Resource nr  3 by     394.31 m3 Natural gas for heat
Perturbed Resource nr  4 by     340.86 kWhe Electricity - imported
Perturbed Resource nr  6 by       0.03 ton Coal for co-combustion
Perturbed Resource nr 26 by       1.00 ha Rapeseed for RME - local
Perturbed Resource nr 52 by      -2.04 ton Animal food (rape seed) - imported
Perturbed Resource nr 57 by      -0.13 ton gl Glycerine - imported
Perturbed Resource nr 58 by      39.40 liter Heavy Fuel Oil
Perturbed Resource nr 59 by      -1.00 ha Set aside land
Perturbed other resources by   3551.54 MJ
--------------------------------------------------------------------------------------------
Effect on fossil energy import in Belgium            -22311 MJ
Effect on renewable energy import in Belgium         -35686 MJ
--------------------------------------------------------------------------------------------
Effect on worldwide fossil energy consumption        -32913 MJp
Effect on worldwide renewable energy consumption      49994 MJp
--------------------------------------------------------------------------------------------
CO2eq saving inside Belgium         238 kg
CO2eq saving outside Belgium       1876 kg
--------------------------------------------------------------------------------------------
Cost                                174 euro
--------------------------------------------------------------------------------------------
Energy efficiency world            0.66 GJp fossil saved world  /GJp renewable produced world
Energy efficiency Belgium          0.45 GJ fossil saved Belgium /GJp renewable produced world
CO2 savings world                  64.2 kg CO2eq world          /GJp fossil saved world
CO2 savings Belgium                10.7 kg CO2eq Belgium        /GJ fossil saved Belgium
Surface requirement Belgium        4.48 are Belgium             /GJ fossil saved Belgium
Surface requirement Belgium         420 are Belgium             /ton CO2eq saved Belgium
Cost requirement Belgium            7.8 euro                    /GJ fossil saved Belgium
Cost requirement Belgium            732 euro                    /ton CO2eq saved Belgium
==============================================================================================
```

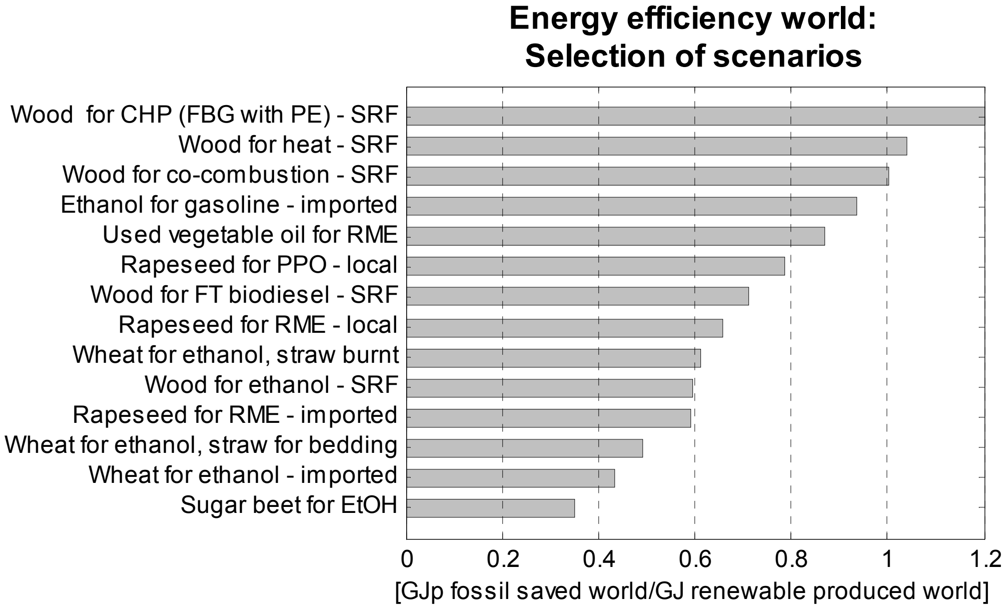

Figure 6-4

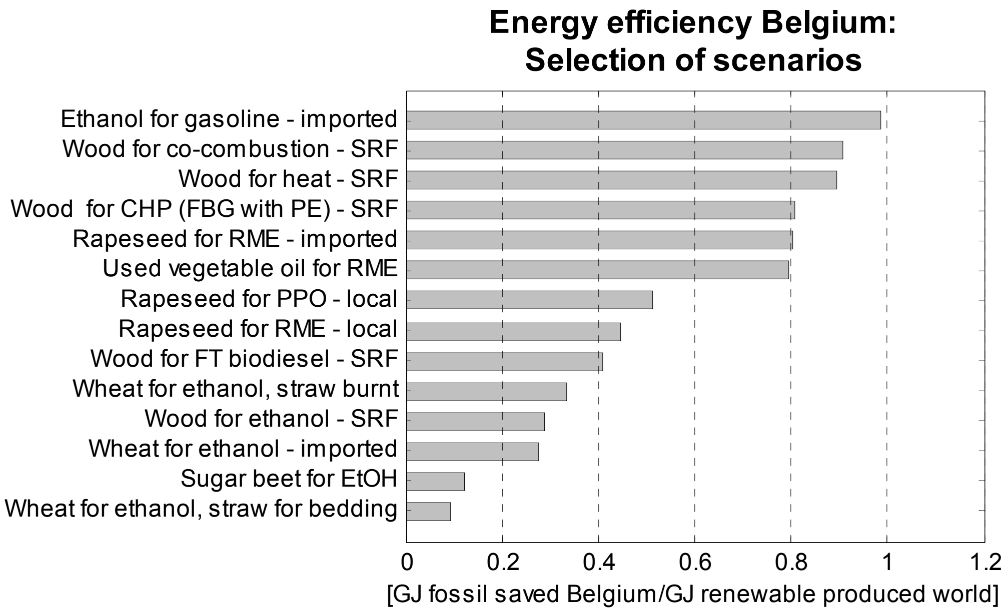

Figure 6-5

Figures 6-5 and 6-7 show the corresponding results but for the Belgian system. Both energy and CO_2 savings in particular are reduced, as a consequence of the energies and CO_2 emitted outside the system. Energy savings in Belgium are particularly low for sugar beat and wheat with straw for animal bedding, with efficiencies as low as 16%. If the fossil energy saving in Belgium is a criterion, preference should be given to wood for heat and/or power, import of ethanol and rapeseed, used vegetable oil and PPO. Other efficiencies remain under 50%. In the case of wheat, the straw should be used for energy recovery in the process to be sufficiently efficient inside Belgium. The FT biodiesel case shows an unexpected low efficiency mainly because the electricity produced is assumed to compensate electricity import. The CO_2 savings show pretty low values for rapeseed and vanish completely for wheat with straw for bedding, which can again be improved by burning the straw. The low values are a combined effect of high N_2O emissions from the land and net import of animal feed in Belgium (see also Figure 6-26). Sugar beat has a surprisingly high CO_2 saving per GJ fossil saved.

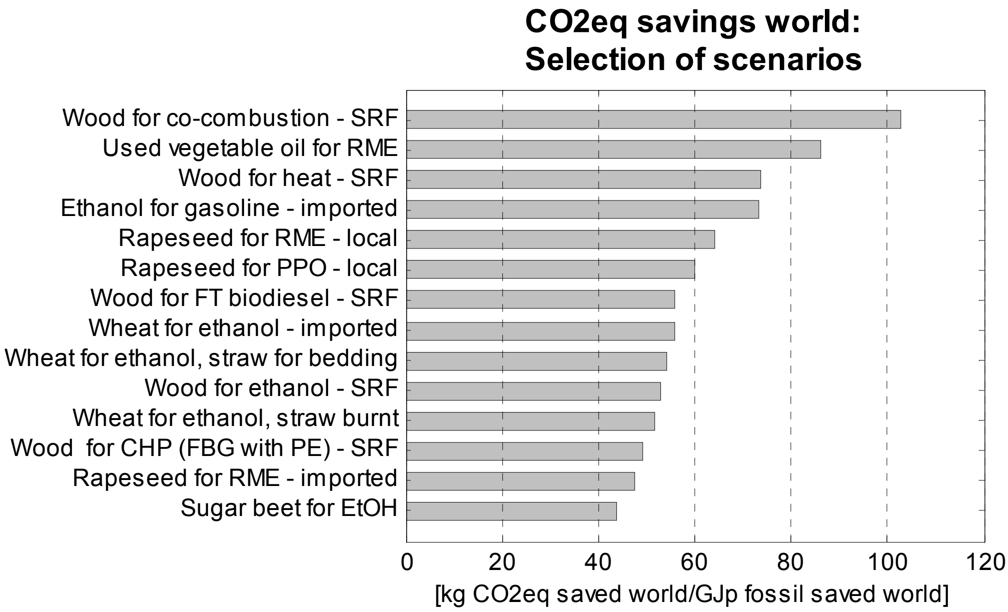

Figure 6-6

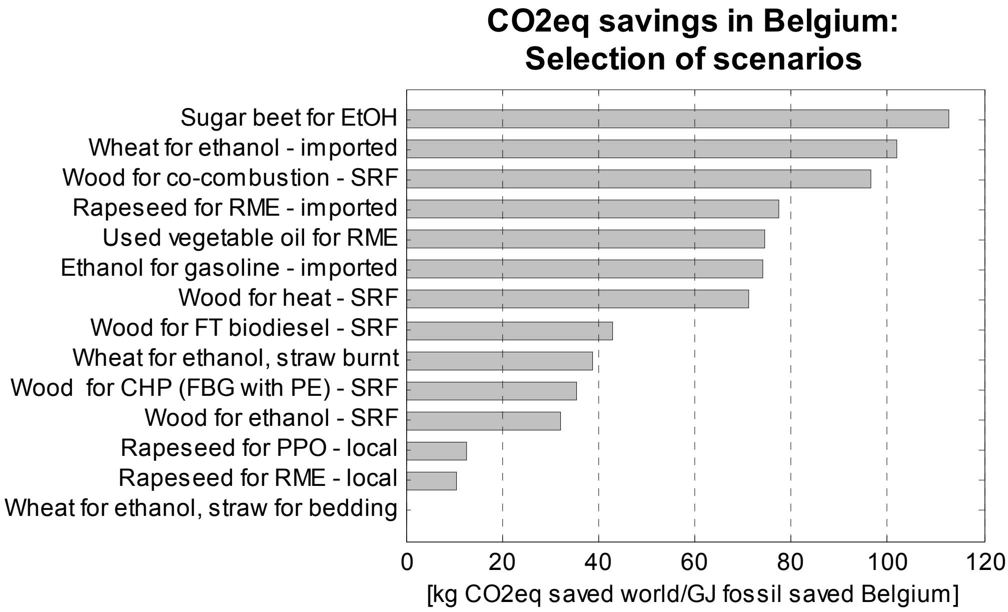

Figure 6-7

All import scenarios yield obviously high CO_2 savings, because CO_2 gains are inside Belgium whereas CO_2 expenses are mainly outside the system! This is a perverse effect, which can however be compensated by CO_2 emission trading on the one hand, and added value from inside production on the other hand. Deeper analysis in the cost structure is therefore required.

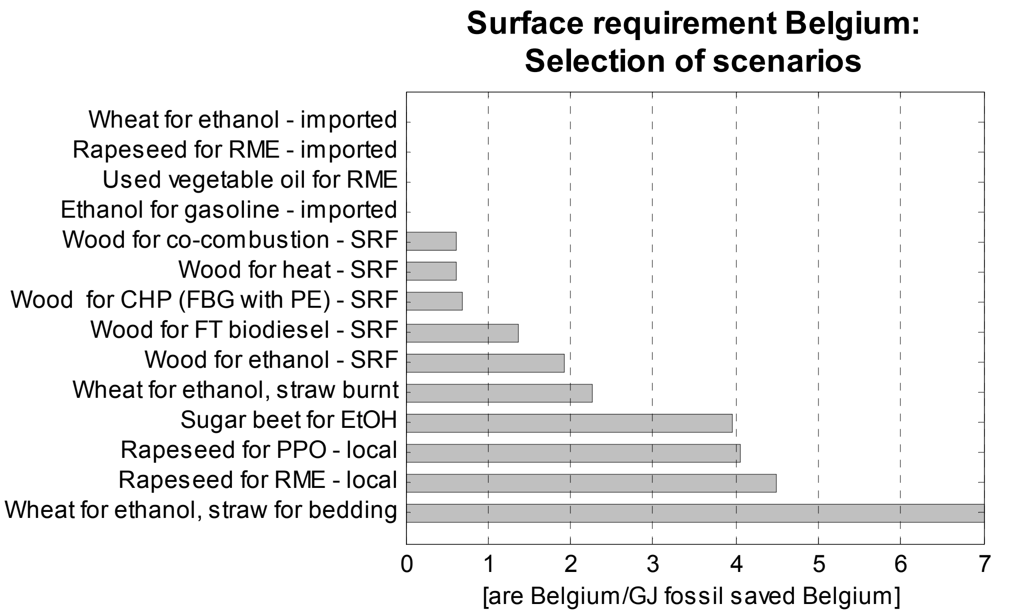

Figure 6-8

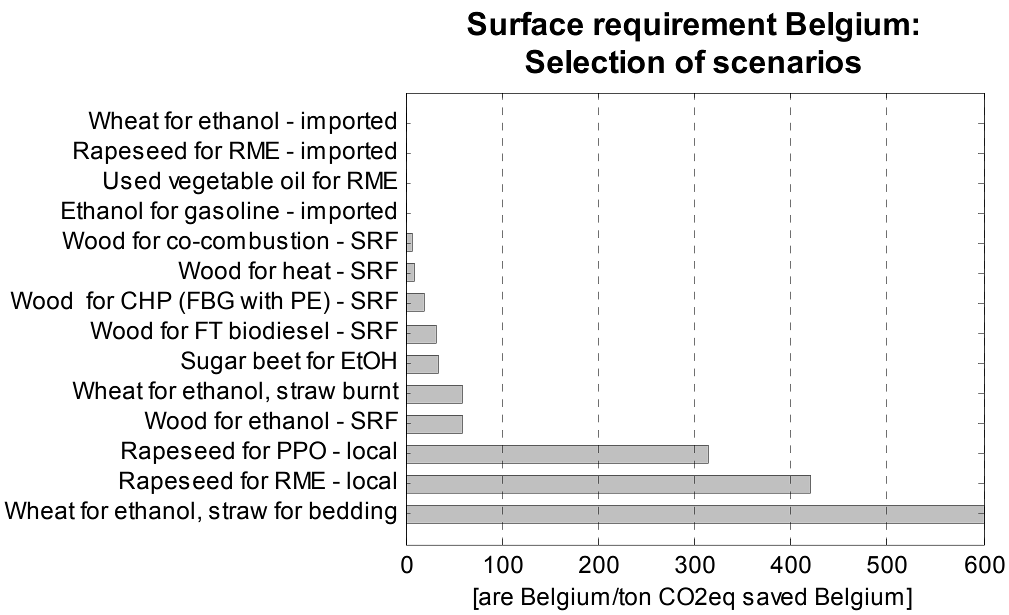

Figure 6-9

Figures 6-8 and 6-9 show the surface requirements for the same scenarios, which is not unimportant in terms of limited availability of land. Figure 6-8 shows the required area per saved fossil GJ, whereas Figure 6-9 shows the required area per saved ton of CO_2eq. Differences are extreme because of a combination of efficiency and yields. The wood for power scenarios combine high values of efficiency and yields, whereas wheat and rapeseed combine poor values. If the available surface is a major criterion and unless the yields can be increased significantly, wood scenario's are by far a primary choice, although growing of short rotation wood is still far from current application.

Figures 6-10 and 6-11 show the cost requirements. As stated before, these cost figures must be taken with care because the economic impacts of the local activity are not really included and costs are therefore higher than the costs found in chapter 4. If all costs are allocated to saved fossil energy (Figure 6-10) costs range gradually from saving some euros per GJ to exuberant costs of 100 euros per GJ. Used vegetable oil and wood for heat appear as the most attractive routes, followed by rapeseed, wood for co-combustion and imported ethanol. Both rapeseed and ethanol from local wheat more or less double the basic fossil price, whereas other scenarios show excessive costs. Allocating the cost to CO_2 (Figure 6-11) yields again a good result for used vegetable oil and wood for heat. Wood for power and imported RME would cost 100 euro/ton CO_2 and all others show higher costs, again if all of the cost is allocated to CO_2.

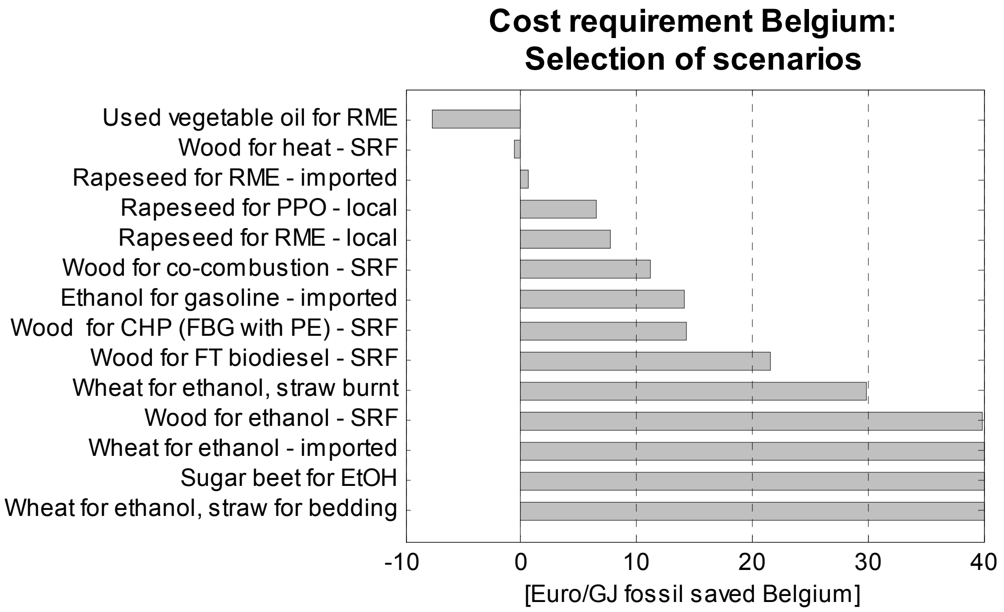

Figure 6-10

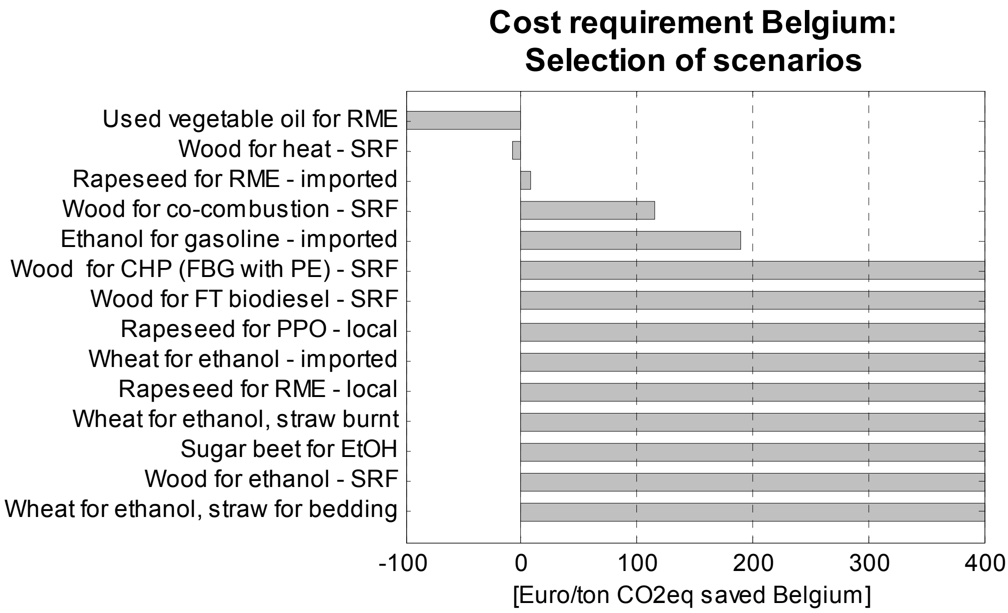

Figure 6-11

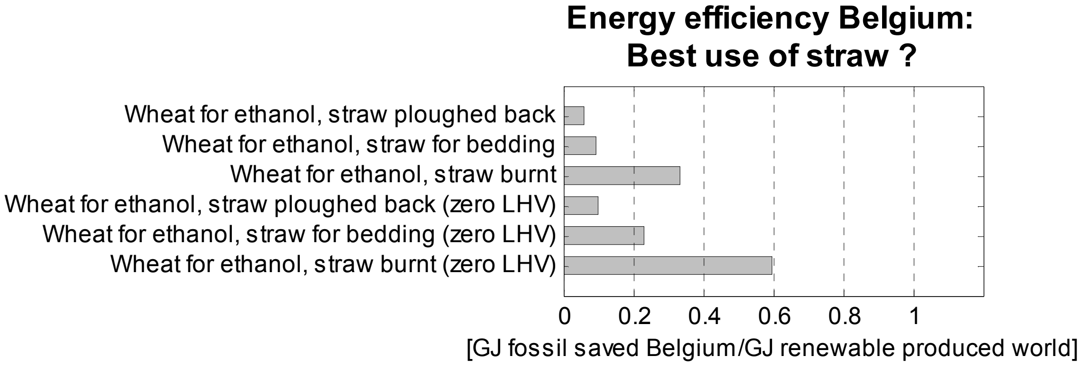

Figure 6-12

Figure 6-12 illustrates different results obtained when modifying the use of the straw obtained from growing wheat. Leaving the straw on the land reduces the global efficiency to a value below 10%. Using the straw for animal bedding reduces the import of straw, and improves the efficiency for the Belgian system to 10%, as already shown before. Burning the straw for heat production purposes in the ethanol conversion process saves a substantial amount of fossil fuel, and the efficiency is more than doubled to some 35%.

These results consider the heating value of the straw to be included in the renewable energy source term, which might be subject to discussion. The calculation can be repeated when considering the straw as a loss (taking a zero LHV), leading to efficiencies which are more or less doubled, with a maximum efficiency close to 60%. The amount of energy in the straw is however too substantial to be considered just as a loss, and efficiencies from wheat are to be considered as rather low due to utilities consumption both at agricultural production and conversion to ethanol. It is to be observed that the produced animal feed (DDGS) absorbs quite some energy for drying, and that this production is compensated by reduced DDGS import.

Figures 6-13 to 6-16 show the differences between replacing a gasoline mixture by ethanol, and using the ethanol to produce ETBE which replaces the MTBE gasoline additive. In theory, the ethanol can also directly replace the MTBE because ethanol has a high octane number, but this intermediate route has disadvantages and is not considered here. From Figure 6-13 it appears that all ETBE scenarios are more efficient worldwide than the ethanol scenarios. This is mainly due to the high utility consumption when making the methanol required for making MTBE (almost as much as its LHV content). This picture is different when considering the Belgian system, as shown in Figure 6-14. Making ETBE is less interesting because the replaced methanol is produced outside Belgium, whereas making the ETBE leads to higher utility usage. This is however not the case when using wood as a resource. A similar conclusion can be drawn for CO_2 emissions in Belgium (Figure 6-15). ETBE costs compare with ethanol costs, except for the wheat case, where ETBE is more expensive (Figure 6-16).

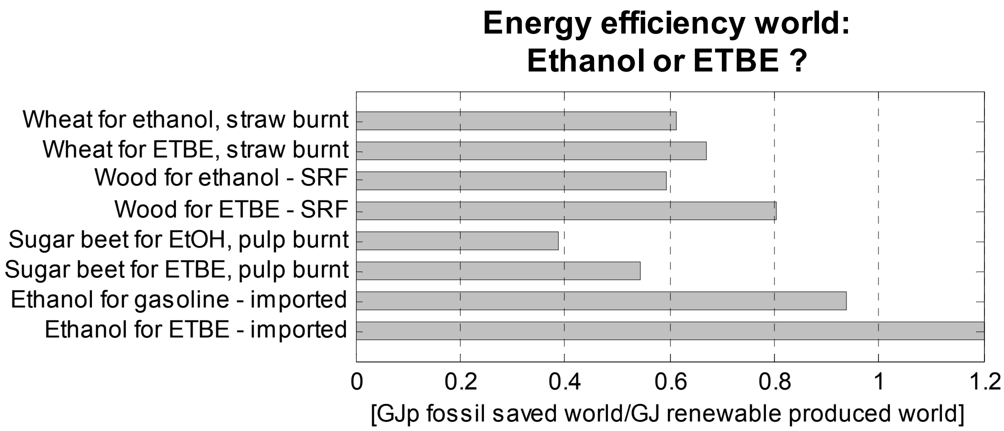

Figure 6-13

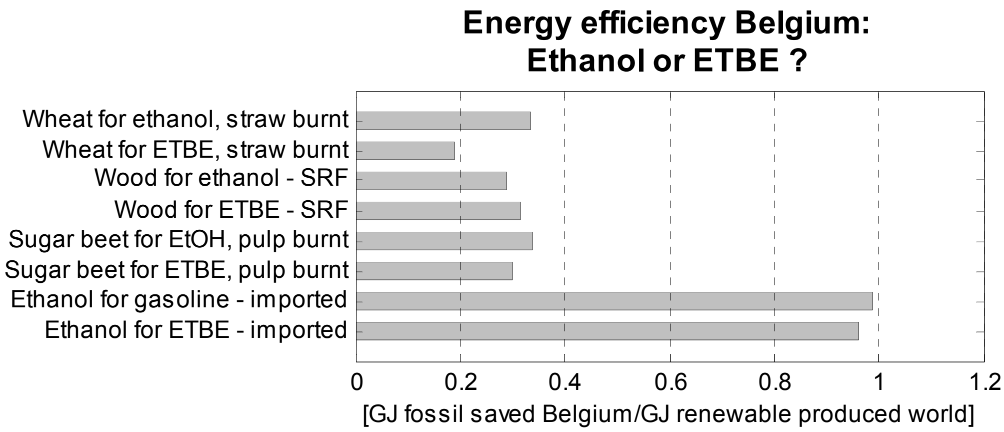

Figure 6-14

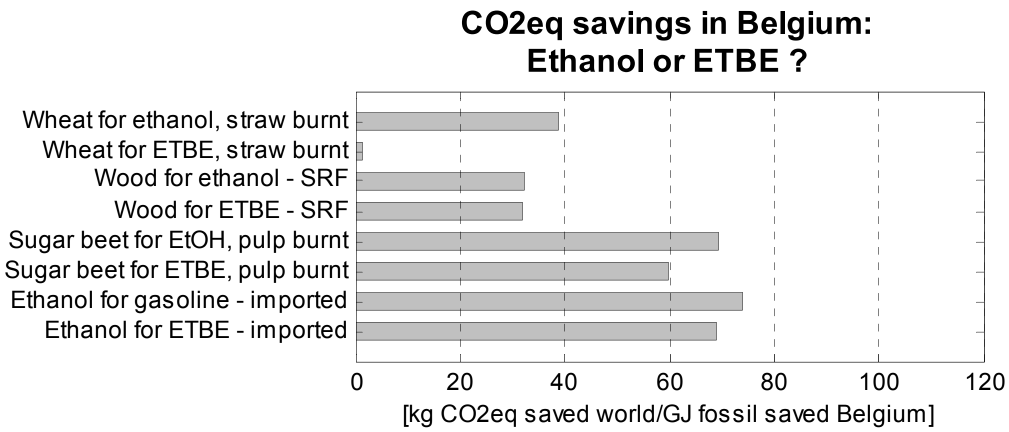

Figure 6-15

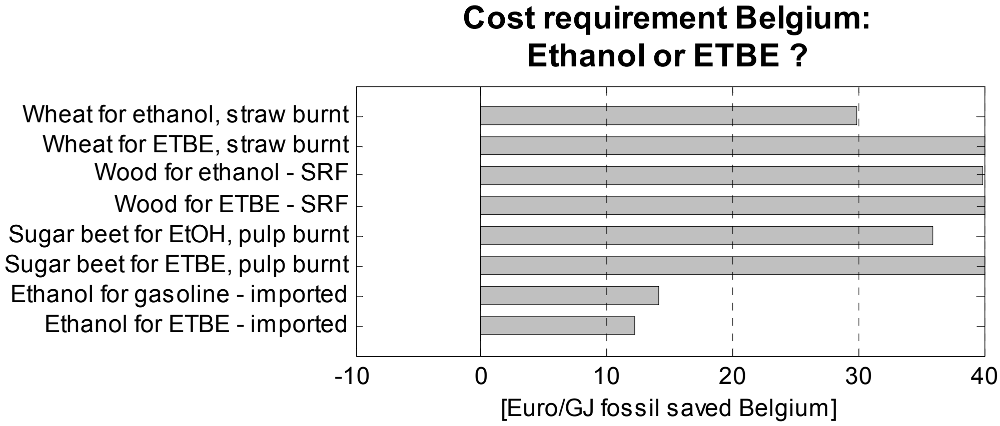

Figure 6-16

Figures 6-17 to 6-24 detail the different possible uses of wood, covering as well heat, CHP, power, ethanol and Fisher-Tropsch Diesel (BTL) production. The Fixed bed gasification case has been included for three wood resources : SRF, forest waste and import, other scenarios assume SRF. Overall efficiencies range from more than 120% in the case of CHP to 60% in the case of ethanol. The small steam power plant for pure electric production is the least efficient with 50%, and should not be an option. 120% efficiency can be explained by the benefit of applying CHP instead of separate production. The efficiency is close to 100% in the case of pure heat production, which means that utility usages in both wood and fossil cases do not differ very much. The co-combustion case shows efficiency larger than one, which is due to reduced long distance transport of hard coal. Fisher-Tropsch Diesel shows 70% efficiency, although CHP is integrated into the conversion process. Efficiencies inside Belgium are again reduced (Figure 6-18), except for co-combustion. This is mostly due to utilities used outside Belgium, in particular for outside electric power production which compensates all the increased inside electric power production, except co-combustion. Looking into the total CO_2 emissions (Figure 6-19) it is found that the CHP scenarios behave less than expected, but this is mainly due to the replaced energy types which are gas and electric power produced outside the system, which is based on an EU mix. CO_2 emissions inside Belgium (Figure 6-20) are close to the total values, except for the ethanol case because of by-products and only little CO_2 is emitted outside the system, except for ethanol.

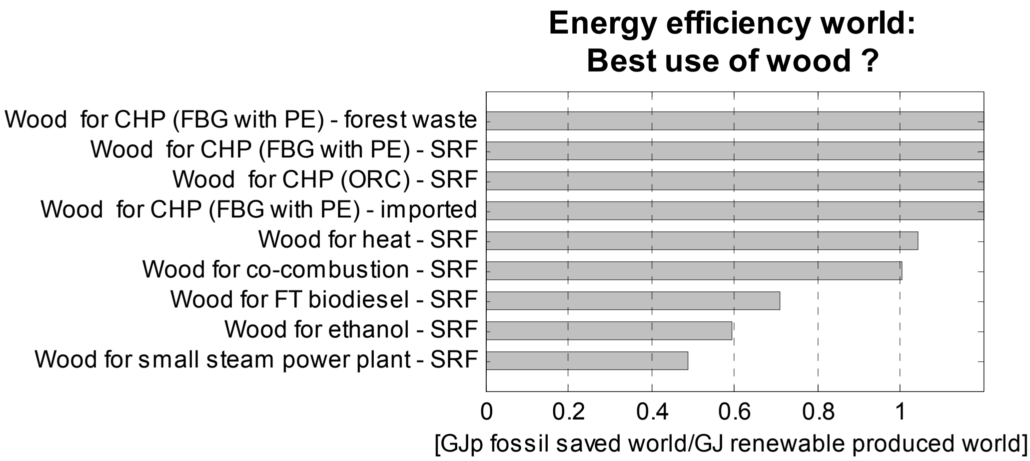

Figure 6-17

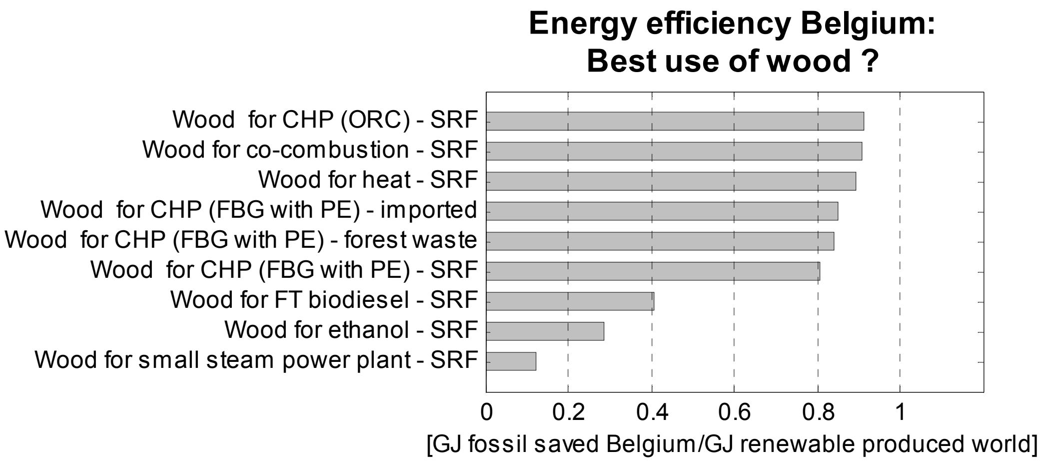

Figure 6-18

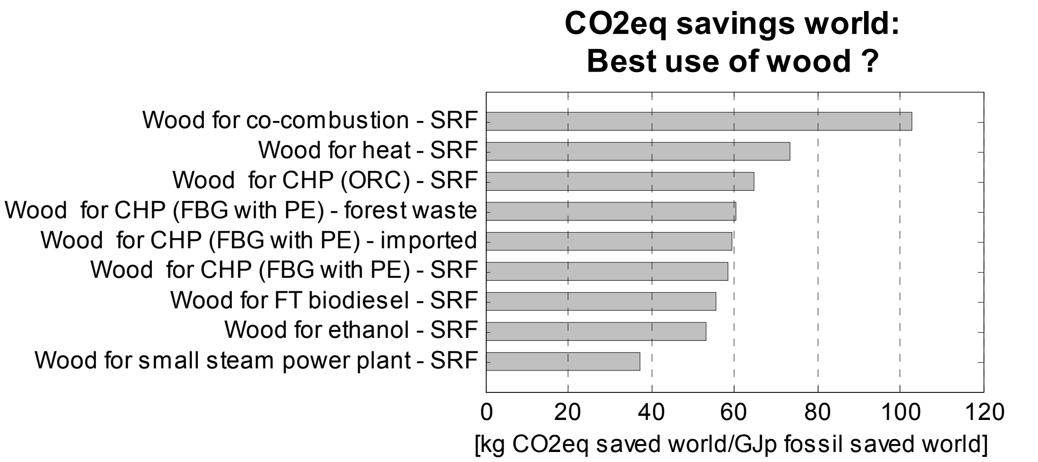

Figure 6-19

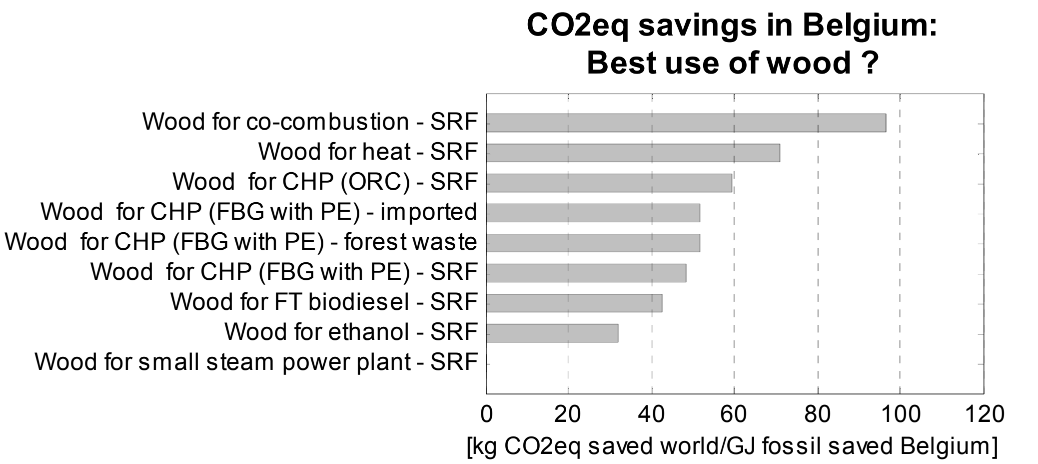

Figure 6-20

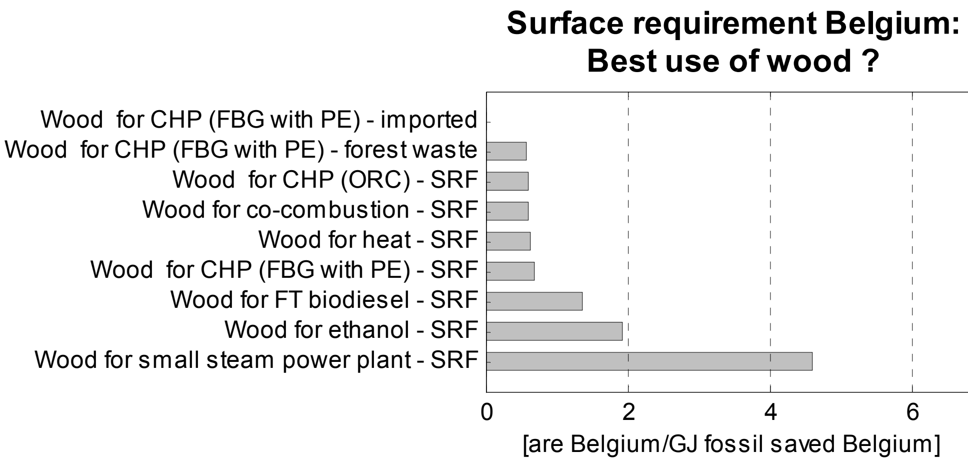

Figure 6-21

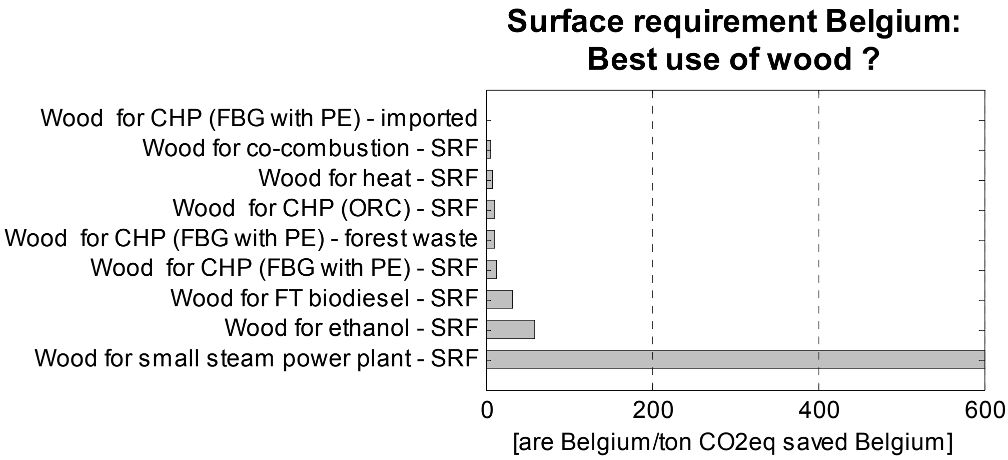

Figure 6-22

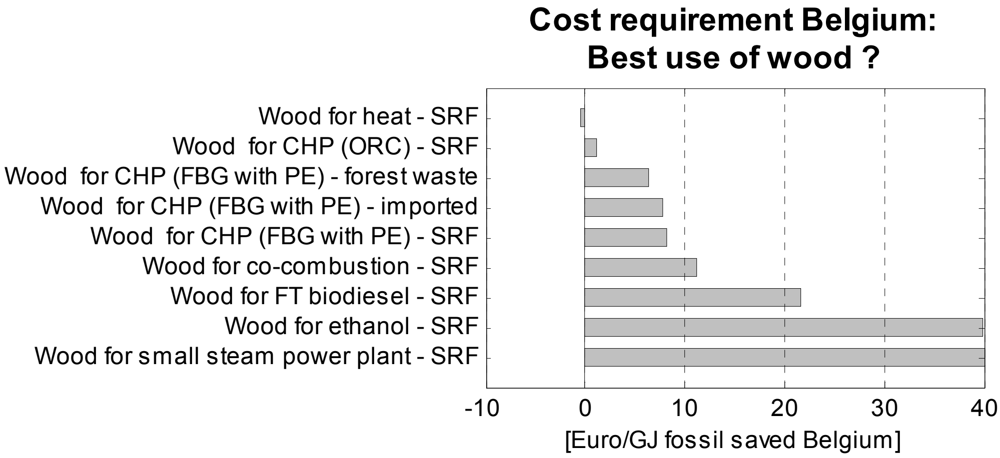

Figure 6-23

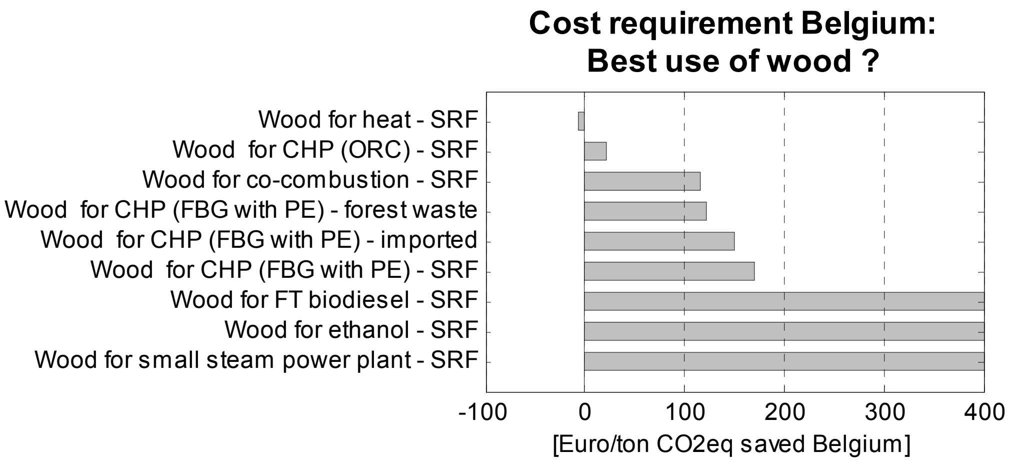

Figure 6-24

Figures 6-25 and 6-26 finally compare import scenarios with scenarios where biomass is produced locally. Wheat, rapeseed and wood are grouped. In the case of wheat and rapeseed differences are a complex result of several main and secondary effects. Wheat is somewhat more efficient, at least when burning the straw, imported rapeseed is more efficient, and is very comparable to imported rapeseed oil. Wood is considered from three sources: short rotation forestry, forest waste and imported wood. Results are quite comparable.

The CO_2 emissions (Figure 6-26) are finally always better for the import scenarios since CO_2 expenses are partly outside the Belgian system, whereas the benefits are inside the system.

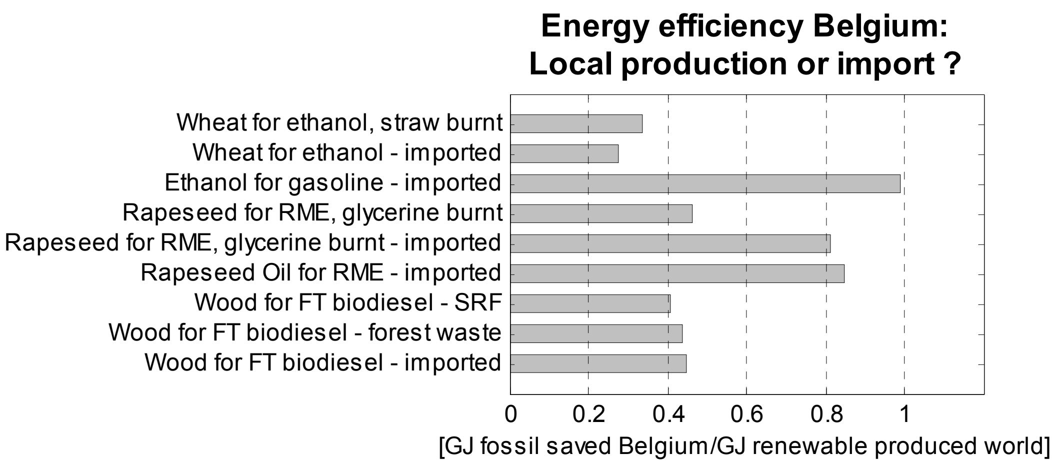

Figure 6-25

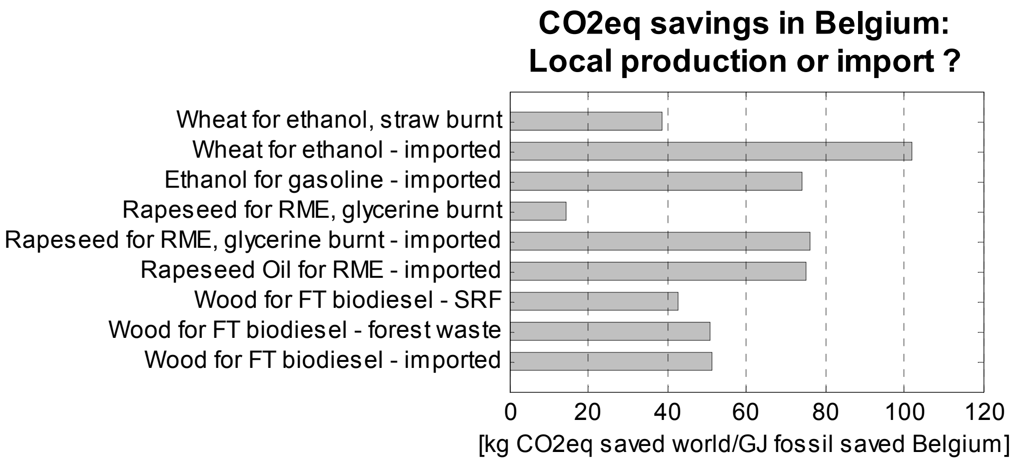
CO2eq savings in Belgium:
Local production or import ?
Wheat for ethanol, straw burnt
Wheat for ethanol - imported
Ethanol for gasoline - imported
Rapeseed for RME, glycerine burnt
Rapeseed for RME, glycerine burnt - imported
Rapeseed Oil for RME - imported
Wood for FT biodiesel - SRF
Wood for FT biodiesel - forest waste
Wood for FT biodiesel - imported
0
20
40
60
80
100
120
[kg CO2eq saved world/GJ fossil saved Belgium]

Figure 6-26

7 CONCLUSIONS AND FUTURE WORK

Approach

The overall objective of the present work was to analyze the behaviour of the most promising biomass routes when applied in Belgium.

An assessment was first made of the biomass production potential in Belgium through available literature and data from national statistics. Since local production is limited and imports are probable, the analysis was extended to a full literature overview on the biomass potential in the EU and further worldwide.

About biomass potential

The energy requirements of Belgium to achieve the European targets set by the 2003/30 directive vary from 530 ktoe to 670 ktoe in 2010. In 2010, we calculated in the present study that Belgium can only supply some 220 ktoe. Thus, Belgium cannot produce sufficient biomass to reach these targets. Some other biomass sources such as barley or maize may provide additional but still limited biomass resources. Moreover, adequate market and fiscal measures and strategic political incentives such as investment incentives, tax relief, feed-in-tariffs, systems of quota and certificates, obligations etc. may help increase the achievable biomass potential.

The biomass demand in Europe can probably be covered with biomass of EU origin. In the year 2010 implementation of the biofuel directive has as consequence that the total European demand for biomass for energy purposes is about 60% of the total estimated technical potential biomass availability in 2010 in the EU25. The demand for other uses of biomass resources (e.g. material) adds up to this figure, and will put further pressure to import biomass from outside the current EU.

Macro-economic aspects

From the macro-economic study it appears that the total amount of imports per GJ biofuel decreases only slightly for biodiesel compared to fossil diesel. Implementation of some of the bioethanol cases leads to even a slight increase of import. These imports are caused by indirect imports from various sectors of the Belgium economy, for example the need for chemicals, additional energy, and also machinery itself (or the material it is made of) is probably for a certain part imported. The feedstock production and conversion, and the distribution of biofuels create much added value in the form of wages, because they are relatively labour intensive.

According to the analysis and with current fossil fuel costs, the excise duty exemption is in general sufficient to cover the extra cost of replacing fossil by renewable fuel. In some cases (rapeseed and rapeseed oil imports, ethanol from sugar beat) the excise duty exemption is however not sufficient to cover the extra costs.

The value added through import of ethanol from Brazil to Belgium is comparable to other options, but this is controlled by the European import tax. If a part of the import tax is rebated to Belgium this would add to the value added for Belgium and import of bioethanol from Brazil would clearly be more attractive than import of rapeseed from Poland and processing in Belgium.

Methodology

A limited number of biofuel routes relevant for Belgian circumstances were next selected. For the environmental sustainability, a full life cycle assessment (LCA) was performed on three selected biofuel chains. The other chains were examined according to IPCC (greenhouse gas balance methods). Another type of analysis was made which is denoted as System Perturbation Analysis (SPA). The SPA computes the impact of a perturbation of the considered system, such as replacing a hectare of set-aside land by a hectare of rapeseed for PPO production, thus reducing the import of fossil fuel, but taking into account all secondary consumptions and by-products which on their turn affect other imports, exports or local productions. As a result, it is possible to determine the best usage of limited resources such as hectares, wood waste, imports or other, in terms of fossil energy savings, GHG emissions and costs, within a given system which in the present case is Belgium.

Life Cycle Analysis and Greenhouse balances

Reduction of fossil energy

All analysed bio-fuel chains lead to a net reduction of fossil energy use and greenhouse gas emissions. On energy basis, the bio-diesel chain requires about 60% less fossil fuel than the diesel chain. In the biodiesel chain, fossil fuel is consumed to equal shares in the feedstock production and the conversion step. In the production of rapeseed feedstock, the larger part (80%) is in fertiliser production, and the remainder mainly in tractor use. In the conversion to bio-diesel, the largest consumer of fossil fuel is the production of methanol from natural gas (38%). Another 19% energy share resides in heat for the bio-diesel plant. Smaller amounts of gas and fuel oil are used for drying the raw rapeseed, and heat in the oil pressing plant.

When driving a car on bio-ethanol instead of gasoline, 40-60% less fossil energy is used. There is a small fossil energy requirement in the agricultural step (fertiliser production and tractor use). The largest demand for fossil energy is in the conversion of wheat to ethanol. This is especially caused by the heat required for distillation. A closer look at the integration of heat, power, and bio-fuels within a bio-ethanol factory could further improve its performance.

Finally, Fischer-Tropsch diesel shows a reduction of about 90% over the use of fossil diesel. The small emission that takes place, almost entirely stems from feedstock production. The conversion from wood to diesel is almost energy neutral, because of the co-production of heat and electricity within the process.

Climate change

Compared to fossil fuels, bio-fuels have a reduced impact on climate change. Bio-diesel performed about 50% better than diesel, bio-ethanol about 20-60% better than gasoline. Fertiliser use had a large impact on climate change in all bio-fuels' chains. This was caused by emission of N_2O during both the production and use of N-fertiliser. The N_2O emissions are expected to reduce significantly however.

The bio-ethanol chains show varied results. Bio-ethanol from wheat has a limited greenhouse gas emission reduction. The emission in agriculture is as high as in the production of biodiesel, but on top of this there are extra emissions from the conversion process. The major part of these emissions stem from energy use (heat) for distillation. This energy could also be supplied from a sustainable source. That would greatly improve the greenhouse gas balance. Ethanol from sugar beet and from sugar cane profit from higher yields per hectare and relatively lower fertiliser input. But the greatest greenhouse gas emission reduction could be realised with the use of ethanol from woody biomass.

There is a large reduction in greenhouse gas emissions when replacing fossil fuels (coal and gas) with biomass to generate heat and / or power. The energy related CO_2 emissions from supplying the biomass are small in comparison with the end-use CO_2 emissions from fossil fuels. Even if better efficiencies were assumed for the fossil alternatives, there would remain a large greenhouse gas advantage for biomass.

Other impacts

The assessed bio-fuels chains perform worse in terms of acidification and eutrophication; this is caused by the agricultural emissions of ammonia, NO_x, SO_x, nitrates and phosphates. End-use emissions relevant for these impact categories are the same for bio-fuels and their fossil alternatives.

System Perturbation Analysis

The SPA approach differs from the LCA, mainly because it aims at studying the Belgian system rather than overall well to wheel process. For comparison and validation purposes the SPA also extends to larger systems, where energetic allocation is applied rather than economic allocations.

Reduction of fossil energy

It appears again that all the scenario's show positive energy balances. The best scores are obtained from the wood to heat and/or power scenarios, with efficiencies even in excess of 100%. This is possible because of the CHP advantage (best case) and positive balances of production and transport energy requirements. Ethanol from import comes on the next place, the ethanol from Brazil being produced at rather low primary energy requirements and CO_2 emissions. RME from used vegetable oil comes next, followed by PPO from rapeseed which is a direct process whilst rape meal is fully recovered as animal feed. Next scenarios show efficiencies around 60%, including wood for FT diesel and ethanol, wheat for ethanol and rapeseed for RME. The straw from the wheat production must be valorised either through combustion or as animal bedding, otherwise the efficiency significantly drops. The sugar beat shows the lowest efficiency, which is due to the high energy requirement in distillation and pulp drying.

Climate change

All overall CO_2 scores are relatively high. The highest score is obtained for wood for co-combustion, mainly because of the high replacement efficiency combined with direct coal replacement. When looking to the Belgian system only, both energy and CO_2 savings in particular are reduced as a consequence of the energies and CO_2 emitted outside the system.

Energy savings in Belgium are particularly low for sugar beat and wheat with straw for animal bedding, with efficiencies as low as 16%. If the fossil energy saving in Belgium is a criterion, preference should be given to wood for heat and/or power, import of ethanol and rapeseed, used vegetable oil and PPO. Other efficiencies remain under 50%. In the case of wheat, the straw should be used for energy recovery in the process to be sufficiently efficient inside Belgium. The FT biodiesel case shows an unexpected low efficiency mainly because the electricity produced is assumed to compensate electricity import. The CO_2 savings show pretty low values for rapeseed and vanish completely for wheat with straw for bedding, which can again be improved by burning the straw. The low values are a combined effect of high N_2O emissions from the land and net import of animal feed in Belgium, which did not appear from the Greenhouse balances made earlier.

All import scenarios yield obviously high CO_2 savings, because CO_2 gains are inside Belgium whereas CO_2 expenses are mainly outside the system! This is a perverse effect, which can however be compensated by CO_2 emission trading on the one hand, and added value from inside production on the other hand. Deeper analysis in the cost structure is therefore required.

The results from LCA and SPA differ, especially in conversion chains where import is involved. Where LCA gives only figures about global fuel consumption and greenhouse gas emissions, SPA allocates emissions according to the place were they are emitted: inside or outside the Belgian system. Therefore, SPA tends to give higher scores to those conversion chains where emissions are shifted outside Belgium, while LCA gives a global picture of greenhouse gas emissions.

Other impacts

When considering local production, the arable land demand per saved GJ fossil energy show a great discrepancy due to combined effects of efficiency and yields. The wood for power scenarios combine high values of efficiency and yields, whereas wheat and rapeseed combine poor values. If the available surface is a major criterion and unless the yields can be increased significantly, wood scenario's are by far a primary choice, although growing of short rotation wood is still far from current application.

Wood scenario's

High to very high energy and CO_2 scores are in general observed when considering woody fuels for heat, CHP and co-combustion applications. Fischer-Tropsch and ethanol from wood show less but still high efficiencies. The small steam power plant for pure electric production is the least efficient with 50%, and should not be an option.
These advantages are hampered in the Belgian case because the produced electric power mainly compensates imported electricity (at least in the present analysis). except for co-combustion where coal is directly replaced.

Future work

The present project has established a workable database for the analysis of biomass for energy applications in general. Further work should be done in analysing the major parameters which affect the conclusions, which are the following :

- N_2O emissions from agriculture
- Raw fossil fuel and biomass market prices
- Cost reductions for emerging technologies such as wood from ethanol and FT diesel

- Assumptions on perturbations of electric power, wheat and animal feed markets in the Belgian system.

The last item needs probably the most effort and is of high importance. In the present study it is assumed that Belgium is net importer of the three products and imports are assumed to decrease in direct proportion to extra local production. In reality the market perturbation is more complex and conclusions from the SPA may be strongly affected. In general conclusion should evolve in a positive direction if imports are less affected.

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Annex A General data, data organisation and detailed results

A.1 Organisation of data and detailed results

Efforts have been made within the project LIBIOFUELS to use as much as possible basic data, from which all intermediate results such as energy consumptions, costs and emissions can be calculated. The impact of fertilisers is for example calculated starting from Table A-1, where the energies consumed from different utilities are detailed for the considered fertilisers and pesticides. Associated indirect energy consumption, all of the CO_2 emissions and energetic costs can next be calculated from Tables A-2 and A-4. The same applies for the transport, where Table A-3 is used far all further computation. Any change in one of these basic Tables therefore propagates automatically throughout all the programmed calculations. This approach reduces the amount of data to be used to a strict minimum, and it also allows for easy sensitivity analysis of any of the basic data from Tables A-1 to A-4.

Annex B details the data used for the logistics, being essentially a distance table and transport types. Annex C shows the basic data about feedstock production. Annex D shows the basic data used for the conversion techniques with corresponding schematic representations of the conversion processes and how the data are used in the calculations. Annex E includes data about the end-use, and Annex F details normalisations of emission coefficients.

For the liquid fuels cases, the majority of the data in Annexes A to D are taken from [CONCAWE, 2003] and [Elsayed et al., 2003], with however additions from other sources as indicated systematically in all the tables. The data for the heat and power production are mostly taken from [Novak et al., 2005] which summarises an overall study of heat and power production from biomass. More details about these heat and power data can be found in a report about embedded power generation, which will be available in the course of 2006.

Annexes I and J are available in a separate volume. Annex I contains detailed results about all calculated primary energies, CO_2 emissions and cost calculations of all the routes listed in Table 6-3 as obtained from the SPA analysis (see example Table 6-1). Annex J finally contains the detailed results from the SPA scenarios (see example Table 6-2).

A.2 General data

Table A-1 contains the amounts of energy consumed to produce the fertilisers used for the considered feedstocks. Indirect energy utilisation and all related CO_2 emissions are calculated from these utility data. CO_2, CH_4 and N_2O emissions other than from utilities are added separately in the rightmost columns.

Table A-2 contains the conversion from CH_4 and N_2O emissions to CO_2 equivalent emissions.

Table A-3 shows the considered utilities consumption for the considered transportation means. Indirect energy utilisation and all related CO_2 emissions are again calculated from these utility data.

Tables A-4 and A-5 finally contain the basic properties and assumed costs of all used material streams.

Table Annex A-1. Utilities consumed and emissions other than caused by the utilities [CONCAWE, 2003, see also Annex C.10]

Fertiliser	Diesel MJ/kg	Natural gas MJ/kg	Electricity MJ/kg	Heavy fuel oil MJ/kg	Hard coal MJ/kg	other CO_2 g/kg	other CH_4 em. g/kg	other N_2O em. g/kg
Nitrogen	0.9	33	0.6	4.4	3.9	1550	5.48	9.63
P	1.1	3.2	1.6	5	0.6	90	1.04	0.0086
K	0.5	7.5	0.2	0	0		0.94	0.0012
CaO	0.2	0.3	0.4	0	0.6		0.27	0.0022
Pesticides	58.1	71.4	28.5	32.5	7.6		19.3	0.152

Table Annex A-2. Conversion and costs to CO_2-eq

Greenhouse gas	conversion to CO_2-eq	
CO_2	1	kg eq/kg
CH_4	23	kg eq/kg
N_2O	296	kg eq/kg
CO_2eq	20	euro/ton

Table Annex A-3. Data for transportation means

Transport type	Energy consumption (MJ/ton.km)	Fuel type
Truck	0.97	gasoil
Ship inshore	0.43	gasoil
Ship offshore	0.2	heavy fuel oil

Table Annex A-4. Overall properties and assumed costs of used material streams

	Lower Heating Value	Density	Utility consumed (outside Belgium)	Direct CO_2 emitted inside B	Total CO_2 emitted outside B	Assumed cost	Assumed cost	Source
	GJ/ton	kg/m3	MJp/GJ	kg/GJ	kg/GJ	euro/GJ	euro/ton	
Crude oil	42.0	820	unknown	not used	unknown	not used	not used	CONCAWE, 2003
DDGS - import 1)	18.2	not used	493	0	28.7	6.2	113	Punter et al., 2004
Electricity	-	-	1869	0	131	18.7	-	Eurostat
ETBE 4)	36.2	750	calculated	calculated	calculated	calculated	calculated	CONCAWE, 2003
Ethanol - import 2)	26.8	794	100	0	9.9	20.5	550	Elsayed et al., 2003
Fueloil (farm/heat)	43.1	832	160	73	14.2	11.6	500	CONCAWE, 2003, FBP
Fueloil (road)	43.1	832	160	73	14.2	14.2	612	CONCAWE, 2003, FBP
Gasoline	43.2	745	140	74	12.5	14.3	618	CONCAWE, 2003, FBP
Glycerine - import 1)	17.0	not used	434	0	126.5	52.9	900	Eurostat
Hard coal	29.4	not used	94	96	15.3	1.7	50	CONCAWE, 2003
Heavy fuel oil	40.5	970	100	81	6.7	10.0	405	CONCAWE, 2003, Petrolfed
Isobutylene 3)	46.0	not used	unknown	68	unknown	10.0	460	IEA, 2005
Methanol	19.9	793	914	69	69.6	7.7	153	CON, 2003. Methanex
MTBE 4)	35.2	746	unknown	calculated	calculated	calculated	calculated	Streicher et al., 1995
Natural gas	44.8	0.64	47	56	4.4	4.1	184	Eurostat
Rapemeal - import 1)	16.4	0	237	0	41.5	6.7	110	CONCAWE, 2003
Rapes. Oil - import 1)	37.5	0	237	0	41.5	13.9	520	CONCAWE, 2003
Rapeseed	23.8	0	0	0	0.0	10.1	240	CONCAWE, 2003
Rapeseed - import 1)	23.8	0	237	0	41.4	8.8	210	CONCAWE, 2003
RME 4)	36.8	890	calculated	calculated	calculated	calculated	calculated	CONCAWE, 2003
SB pulp - imported 1)	15.6	0	840	0	0.1	3.2	50	CONCAWE, 2003
Straw - import 1)	14.6	0	85	0	13.3	3.4	50	Punter et al., 2004
Sugar beet	3.8	0	0	0	0.0	13.0	50	CONCAWE, 2003
Used vegetable oil	37.5	0	237	0	41.5	6.7	250	Vito, 2001
Wheat	17.0	0	0	0	0.0	6.0	140	CONCAWE
Wheat - Import	17.0	0	85	0	13.3	8.5	145	CONCAWE, 2003
Wood	18.0	0	0	0	0.0	10.3	185	CONCAWE
Wood - for. waste	18.0	0	0	0	0.0	8.9	160 81?	CONCAWE, 2003
Wood - import 1)	18.0	0	5	0	0.3	10.2	183	CONCAWE, 2003

1) Primary energy and CO_2 emissions are obtained by energetic allocation, starting from the Belgian situation as calculated in the present report.

2) The ethanol primary energy requirement and CO_2 emissions are based on data from http://www.mct.gov.br/clima and Moreira et al. (1999)

3) Isobutylene is an intermediary product and it is difficult to allocate energy, CO_2 and cost. The amount of used isobutylene in the SPA is however almost unperturbed, because replacing MTBE by ETBE consumed almost the same amount of isobutylene. The unknown values have been set to 0.

4) Some of these data are not basic data, but can be calculated through LCA, GHG balance or SPA (see details Annexes G)

Table Annex A-5. Overall properties of extra material streams (Elsayed et al., 2003)

Material	Utility consumed MJp/kg	CO_2-eq emitted g/kg
Hexane	52.0	564
H_3PO_4	11.4	805
NaOH	19.9	1200
KOH	40.3	2131
Limestone	0.6	20.6

Annex B Specification of chain logistics

Table Annex B-1. Loads and allocated distances for biofuel chains transport steps as collected from libiofuels workshops

#	Chain	Feedstock origin	Transport step	Typical units	
1	PPO from rapeseed	Belgium	Tractor field to farm	8	tonne
				5	km
2a	Biodiesel from rapeseed	Belgium	Tractor field to farm	8	tonne
				5	km
			Truck farm to central storage	28	tonne
				10	km
			Truck depot to factory	28	tonne
				50	km
			Barge factory to blending	1,000	tonne
				150	km
			Distribution by truck	28	tonne
				100	km
2b	Biodiesel from rapeseed	Poland	Ship (rapeseed) to Ghent	70,000	tonne
				1,800	km
			Barge Ghent to factory Wallonia	1,000	tonne
				150	km
			Barge factory to blending	1,000	tonne
				150	km
			Distribution by truck	28	tonne
				100	km
2c	Biodiesel from rapeseed oil	Canada	Ship (rapeseed oil) to Ghent	70,000	tonne
				6,600	km
			Barge Ghent to factory Wallonia	1000	tonne
				150	km
			Barge factory to blending	1,000	tonne
				100	km
			Distribution by truck	28	tonne
				100	km
2d	Biodiesel from Waste Vegetable Oil	Belgium	Truck collection to factory	28	tonne
				100	km
			Barge factory to blending	1,000	tonne
				150	km
			Distribution by truck	28	tonne
				100	km

Table Annex B 1 c'd. Loads and allocated distances for biofuel chains transport steps

#	Chain	Feedstock origin	Transport step	Typical units	
3a	Bioethanol from wheat	Belgium	Tractor field to farm	8	tonne
				5	km
			Truck farm to central storage	28	tonne
				10	km
			Barge central storage to factory	1,000	tonne
				80	km
		Poland	Ship (wheat)	70,000	tonne
				1,800	km
			Barge to factory Wallonia	1,000	tonne
				150	km
			Barge factory to blending	1,000	tonne
				150	km
			Distribution by truck	28	tonne
				100	km
3b	Bioethanol from sugar beet	Belgium	Truck field to factory	28	tonne
				50	km
			Barge factory to blending	1,000	tonne
				150	km
			Distribution by truck	28	tonne
				100	km
3c	Bioethanol from sugar cane	Brazil	Ship (ethanol)	100,000	tonne
				9,700	km
			Distribution by truck	28	tonne
				100	km
3d	Bioethanol from wood	Belgium	Truck forest to factory	28	tonne
				100	km
			Barge factory to blending	1,000	tonne
				100	km
			Distribution by truck	28	tonne
				100	km
3e	Bioethanol from wood	Canada	Ship (wood)	70,000	tonne
				6,600	km
			Barge harbour to factory	1,000	tonne
				100	km
			Barge factory to blending	1,000	tonne
				100	km
			Distribution by truck	28	tonne
				100	km
4a	BTL from wood	Belgium	Truck field to factory	28	tonne
				100	km
			Barge factory to blending	1,000	tonne
				100	km
			Distribution by truck	28	tonne
				100	km
4b	BTL from wood	Canada	Ship (wood)	70,000	tonne
				6,600	km
			Barge harbour to factory	1,000	tonne
				100	km
			Barge factory to blending	1,000	tonne
				100	km
			Distribution by truck	28	tonne
				100	km

Table Annex B-2. Distances for and loads of transportation steps specified for fuel reference chains.

Ref	Gasoline or diesel from fossil oil	International transport	According to databases	
		Distribution by truck	28	tonne
			100	km

Table Annex B-3. Distances and loads of transport steps specified for heat and/or power chains.

#	Feedstock origin	Transport step	Typical units	
5a, 6a, 7a, 8a, 9a (locally produced wood and waste wood)	Belgium	Truck field to factory	28	tonne
			100	km
5b, 6b, 7b, 8b, 9b [imported wood (pellets)]	Canada	Ship (wood)	70,000	tonne
			6,600	km
		Barge harbour to factory	1,000	tonne
			100	km

Annex C Assumptions on feedstock production

C.1 Production of rapeseed in Belgium

Table Annex C-1. Rapeseed growth and harvest in Belgium.

Process/material	Values applied		Source
Yield seeds	3.6 tonne/ha/yr	10% moisture	INS - NIS
Yield straw	2.5 tonne/ha/yr		INS - NIS
Fertiliser[1)]	180 kg N/ha/yr (CAN) 65 kg K_2O /ha/yr 90 kg P_2O_5/ha/yr 21.5 kg CaO/ha/yr		CONCAWE, 2003
Plant protection[1)] Butisal Plus Targa Horizon CCC Karate	 1 l/ha/yr 0.75 l/ha/yr 1 l/ha/yr 0.5 l/ha/yr 0.8 l/ha/yr	 500 g/l 125 g/l 250 g/l 460 g/l 25 g/l	Jossart et al., 2005
Seed material	4 kg/ha/yr	6.87 MJ/kg 300 g CO_2/kg	Elsayed et al., 2003
N_2O land emissions	5 kg/ha/yr		CONCAWE, 2003
Machinery[2)] Soil operations Planting / sowing Crop protection Harvest and processing	 5.5 h/ha/yr 1.1 h/ha/yr 2.3 h/ha/yr 2.6 h/ha/yr	 18 l fueloil/h 10.6 l fueloil/h 6.6 l fueloil/h 6.6 l fueloil/h	CONCAWE, 2003
Economic allocation	91% to rapeseed		Calculation[3)]
Energetic allocation	5.6 GJ/tonne 986 kg CO_2/tonne		Calculation[4)]

1) For comparison, FAO suggests 150 kg N/ha/yr, 50 kg P2O5/ha/yr and 150 kg K2O/ha/yr for Belgium [FAO statistical data].

2) In KWIN, machinery sums up to 119 kg diesel/ha/yr.

3) Allocation depends on the use of the co-product. Rapeseed 210 €$_{2000}$/tonne [PAV, 2000], assumed straw same as wheat straw 50 €/tonne [PAV, 2000]. Assumed costs for rape straw harvesting 21 €/tonne, same as wheat straw. Result is 91% allocation to rapeseed.

4) Allocation based on extrapolation from annex D

C.2 Production of winter wheat (Belgium)

Table Annex C-2. Winter wheat growth and harvest in Belgium.

Process / material	Value assumed		Source
Yield seeds[1)]	8.8 tonne/ha/yr	16% moisture	Elsayed et al., 2003
Yield straw[2)]	4.4 tonne/ha/yr		KWIN, 2002
Fertiliser[3)]	185 kg N/ha/yr (CAN) 50.2 kg K_2O/ha/yr 72 kg P_2O_5/ha/yr 8.7 kg Ca/ha/yr		CONCAWE, 2003
Plant protection[3)]			Rosenberger et al. 2001
Isoproturon	2 l/ha/yr	500 g/l	
Bifenox	2 l/ha/yr	460 g/l	
mecoprop-p	2 l/ha/yr	190 g/l	
chlormequat	1 l/ha/yr	720 g/l	
epoxicanazole	1 l/ha/yr	125 g/l	
azoxystrobine	0.5 l/ha/yr	250 g/l	
Seed material	185 kg/ha/yr	13.5 MJ/kg 870 g CO_2/kg	Punter et al., 2004
N_2O land emissions	5.2 kg/ha/yr		CONCAWE, 2003
Machinery			CONCAWE, 2003
Tillage	1.9 h/ha/yr	18 l fueloil/h	
Seedbed preparation	0.9 h/ha/yr	18 l fueloil/h	
Sowing	0.75 h/ha/yr	7 l fueloil/h	
Fertilisation	0.5 h/ha/yr	12 l fueloil/h	
Crop protection mechanical	2.6 h/ha/yr	12 l fueloil/h	
Other agricultural activities	2 h/ha/yr	4 l fueloil/h	
Economic allocation[5)]	92% to wheat		Calculation[4)]
Energetic allocation	1.44 GJ/ton 226 kg CO_2/ton		Calculation[5)]

1) 8.4 tonne/ha/yr in Dutch quantitative information on agriculture [PAV, 2000]. In literature, a range is found from 5.4 to 9 tonne/ha [Van den Broek, 2003].

2) 4.4 tonne/ha/yr [KWIN].

3) For comparison, FAO suggests 155 kg N/ha/yr, 25 kg P_2O_5/ha/yr and 40 kg K_2O/ha/yr for Belgium [FAO statistical data]. Winter wheat production in Great Britain overall applied 187 kg N/ha, 43 kg P_2O_5/ha and 48 kg K_2O/ha [Goodlass et al., 2003].

4) Allocation depends on the use of the co-produced straw. Wheat 127 $€_{2000}$/tonne [KWIN], Straw 50 $€_{2000}$/tonne [KWIN] or 25 pound/tonne [Elsayed, 2003] when applied as bed material. Straw harvesting costs 21 $€_{2000}$/tonne [KWIN].

5) Allocation based on extrapolation from annex D

C.3 Production of sugar beet (Belgium)

Table Annex C-3. Sugar beet growth and harvest in Belgium.

Process / material	Value applied		Source
Yield	67.1 tonne/ha/yr	75% moisture	Elsayed et al., 2003
Fertiliser[1)]	103 kg N/ha/yr (CAN) 125.3 kg K_2O /ha/yr 87 kg P_2O_5/ha/yr 40 kg CaO/ha/yr		CONCAWE, 2003
Plant protection Chloradizon Fenmedifam Metamitron Ethofumesaat Mineral oil	 2 litre/ha/yr 2 litre/ha/yr 3 litre/ha/yr 2 litre/ha/yr 1.2 kg/ha/yr	 650 g/l 157 g/l 700 g/l 200 g/l	CONCAWE, 2003
Seed material	3.8 kg/ha		Punter et al., 2004
N_2O land emissions	2.6 kg/ha		CONCAWE, 2003
Machinery[2)] Soil preparation Planting / sowing Crop protection Harvest and processing Fertiliser application Cutting and ensiling	 6.9 h/ha/yr 0.8 h/ha/yr 3.5 h/ha/yr 14.5 h/ha/yr 17.9 h/ha/yr 98.4 h/ha/yr	 18 l fueloil/h 7 l fueloil/h 12 l fueloil/h 7 l fueloil/h 12 l fueloil/h 18 l fueloil/h	CONCAWE, 2003
Economic allocation	100% to sugar beet		
Energetic allocation	n.a.		

1) For comparison, FAO suggests 110 kg N/ha/yr, 50 kg P_2O_5/ha/yr and 155 kg K_2O/ha/yr for Belgium [FAO statistical data].

2) KWIN [2002] reports a total of 121 litre/ha/yr for 55 tonne/ha sugar beet yield. This equals some 124 kg diesel/ha for the yield of 67.1 tonne/ha/yr. This is a factor 15 lower. The value of KWIN has been used for the LCA, SPA has used the data from the table..

C.4 Production of sugar cane (Brazil)

Damen [2001, Table C-4] describes the production of ethanol from sugar cane in Brazil for the short and longer term.

Table Annex C-4. Sugar cane growth and harvest in Brazil [Damen, 2001]

Yield[1)]	75 tonne/ha/yr (73% moist)
Machinery use	195 kg fueloil/ha/yr
Fertiliser use	74.4 kg/ha/yr

1) Actual yield per plot is 90 tonne/ha/yr, but there are 5 cuts in 6 years.

2) Damen [2001] reports that the primary energy contained in the used fertiliser is 3863 MJ/yr. We assumed that the primary energy required for the production of fertiliser is 51.9 MJ/kg

C.5 Production of Short rotation coppice (Belgium)

Table Annex C-5. Short rotation willow forestry in Belgium[1].

Process / material	Value applied		Source
Yield [2]	10 tonne/ha/yr	dry tonnes	Londo et al., 2004
Fertiliser [3]	108 kg K_2O/ha/yr 60 kg P_2O_5/ha/yr 75 kg N/ha/yr		Van den Broek et al., 2002
Plant protection[4]			Van den Broek et al., 2002
Glyphosate	0.75 kg/ha/yr		
Machinery[6]			
Tillage	1.9 h/ha/lifetime[5]	18 l fueloil/h	Van den Broek, 2000
	1.5 h/ha/lifetime	10.6 l fueloil/h	
Planting	2.5 h/ha/lifetime	10.6 l fueloil/h	Van den Broek, 2000
Fertilisation	0.5 h/ha/yr	7 l fueloil/h	Van den Broek, 2000
Initial weeding (5 times)	2.5 h/ha/lifetime	7 l fueloil/h	Van den Broek, 2000
(2 times)	4 h/ha/lifetime	10.6 l fueloil/h	
Cutting	1.2 h/ha/lifetime	10.6 l fueloil/h	Van den Broek, 2000
	0.6 h/ha/lifetime	44 l fueloil/h	
Harvest (6 times)	45 h/ha/lifetime	18 l fueloil/h	Van den Broek, 2000
	15 h/ha/lifetime	44 l fueloil/h	
Post Harvest weeding (5 t)	2.5 h/ha/lifetime	7 l fueloil/h	Van den Broek, 2000
	3 h/ha/lifetime	7 l fueloil/h	
Post cultivation	0.6 h/ha/lifetime	7 l fueloil/h	Van den Broek, 2000
	5 h/ha/lifetime	10.6 l fueloil/h	
Fences (total)	480 MJ/year		Elsayed et al., 2003

1) In Belgium short rotation plantations have been researched experimentally (University of Antwerp); there was no use of fertilizers and the yields obtained were not very high (about 6 ton/year) [Lavric, 2005].

2) Initial moisture content is as high as 35%; the willow remains in the field for a couple of months to dry down to about 20% moisture.

3) Fertilization [Van den Broek 2000, and Van den Broek 2002] is assumed to take place every year with a chemical fertilizer spreader. Possibly, more fertilizer is given during the first years of each harvest rotation because it may not be possible to enter the field in the third and/or the fourth year of each harvest rotation. In other sources, the quantities of fertilizers used are one order of magnitude lower (N: 781.5 mg/kg dry biomass; 208.3 mg phosphorus/kg dry biomass; 364.9 mg potassium/kg dry biomass; 28.7 mg pesticide/kg dry biomass [Lynd et al., 2004]). Londo et al. [2004] state that the fertilization (and also the protection against weeds) can be from absent to intensive in the case of willow SRF with optimum values of about 60 – 120 kg/ha for N, 20 – 50 kg/ha for phosphorus and 0.7 kg a.i. biocides/(ha·year).

4) After each harvest chemical weed control is undertaken by spraying glyphosate. After the end of the plantations' lifetime, the remaining trunks are killed with glyphosate.

5) The willow plantation lifetime is assumed to be 25 years, during which 6 harvests are undertaken; the first harvest after 5 years and subsequent harvests each after 4 years.

6) SPA uses the table data as given. LCA uses a total of 190 kg fueloil/ha/yr (2 to 4% of the produced energy).

C.6 Use of green fallow land (Belgium)

Table Annex C-6. Green fallow land in Belgium[1].

	Value applied
Sowing seeds	20 kg/ha/yr
Fertiliser	30 kg N/ha/yr (CAN)
Machinery	
Soil operations	3.3 h/ha/yr
Planting / sowing	0.9 h/ha/yr
Crop protection	0.3 h/ha/yr
Harvest and processing	2.4 h/ha/yr

1) Dutch data are assumed [KWIN].

C.7 Use of forest residues (Belgium)

Table Annex C-7. Forest residues in Belgium[1]

	Value applied
Yield	11.4 ton dry/ha/yr
Regeneration	534 MJp/ha 23.7 kg CO_2/ha
Harvesting	419 MJp/ha 29 kg CO_2/ha
Extraction	53 MJp/ha 5 kg CO_2/ha
Chipping	46 MJp/ton dry 5.1 kg CO_2/ha

1) Source : Calculated from Elsayed et al., 2003

C.8 Production and application of pesticides

The production of pesticides is not included in databases, except for a generic pesticide. For the production process, energy use and greenhouse gas emissions are assumed more important than other (toxic) emissions. Also, the toxic emissions from application of the fertilisers are assumed to contribute more to environmental impacts than emissions from production. Therefore we assume that a certain amount of this generic pesticide is produced corresponding to the total amount of active components in the actually necessary pesticides.

The application of 1 kg pesticides leads to a direct soil emission of that pesticide of 0.5 kg, a direct air emission of 0.1 kg and a direct water emission of 0.01 kg [Van den Broek 2000]. The impact of these emissions on the aquatic and marine water, on sediments, on the soil and the human being are known for most, but not for all pesticides. For unknown pesticides, the average impact from used known pesticides is applied.

Table Annex C-7. Identification of pesticides and availability of impact information.

Active component	CAS numbers[1)]	Impact information available
Mecoprop	7085-19-0	Yes
Fluroxypyr	69377-81-7	Yes
Chlormequat	7003-89-6	Yes
Epoxyconazole	135319-73-2 (formerly 106325-08-0);	Banned by European commission?
Fenpropimorph	67564-91-4	yes
Pirimicarb	23103-98-2	yes
Chloradizon	1698-60-8	yes
Fenmedifam	13684-63-4	no
Metamitron	41394-05-2	yes
Ethofumesate	26225-79-6	no
Metazachlor	67129-08-2	yes
Fluazifop-p-butyl	69806-50-4	no
Flea beetle spray		no
Mineral oil		yes

1) Impact assessment database CML and various websites: http://environmentalchemistry.com/; http://www.hclrss.demon.co.uk/

C.9 Nutrient balances in agriculture

Emissions as a result of fertilisation are assessed by means of a nutrient balance. Different studies have described (parts of) this balance. The IPCC applies a generic method to calculate the N_2O emissions from agriculture, which is also applied in the Libiofuels project.

IPCC method

Generally, the emissions of N_2O from agriculture can be calculated by the IPCC default method. This is a generic (black box) method that calculates the emissions from the applied N in fertiliser. Countries have to report their emissions to the UN FCCC (by National communications) using this default method, unless they have a scientifically based and documented alternative method. At this moment, neither Belgium nor our neighbouring countries have such an alternative method implemented.

The amount of N applied as N-fertiliser (synthetic or manure) is called the N-applied. Of the applied N, IPCC assumes that 10% volatilises to NH_3 in the case of synthetic fertiliser. In the case of animal manure and urine this is 20%. Van den Broek [2000] assumes that only 2% of the N in synthetic fertilisers volatilises to NH_3 in Dutch agriculture, as most of the fertilizer used is calcium ammonium nitrate, while the high IPCC value is merely based on the application of fertilisers such as urea and aqueous ammonia [van Groenigen 2005]. Emissions from manure may also be much lower than in surrounding countries (< 5%) due to low-emission application techniques applied in the Netherlands. 1% of the N in emitted NH_3 is assumed to be converted to N_2O, but less NH_3 and more N_2O may result from specific application techniques for manure in the Netherlands (2% instead of 1%).

The default value for direct soil emission of N_2O from synthetic fertiliser within the IPCC method is 1.25% (0.25–2.25%) of the applied N. This is the emission from fertilized plots minus the emission from unfertilized control plots [Bouwman et al. 2002]. For animal manure in the Netherlands this emission is 2%.

Of the applied N, according to IPCC eventually 30% is leached as nitrate (NO_3^-) to groundwater. The IPCC states that of this NO_3^-, 2.5% is indirectly emitted as N_2O in the deeper soil, drainage ditches, etc. It does not matter very much how deep the groundwater is [van Groenigen 2005].

Mineralised N in crop residues behaves just like N applied as fertiliser, with the same direct N_2O emissions. The IPCC does not explicitly account for nitrate leaching from crop residues. The IPCC does apply one direct emission factor of 1.25% as N_2O from the total amount of N in residues that are returned to the soil [Velthof et al. 2000], being the same as applied for direct N_2O emissions from fertilizer application. The total amount of N in residues is estimated from FAO statistics on total crop yields, assuming that half of the N is in harvested crops and half in the residue, combined with a default fraction N (45%) removed from the field.

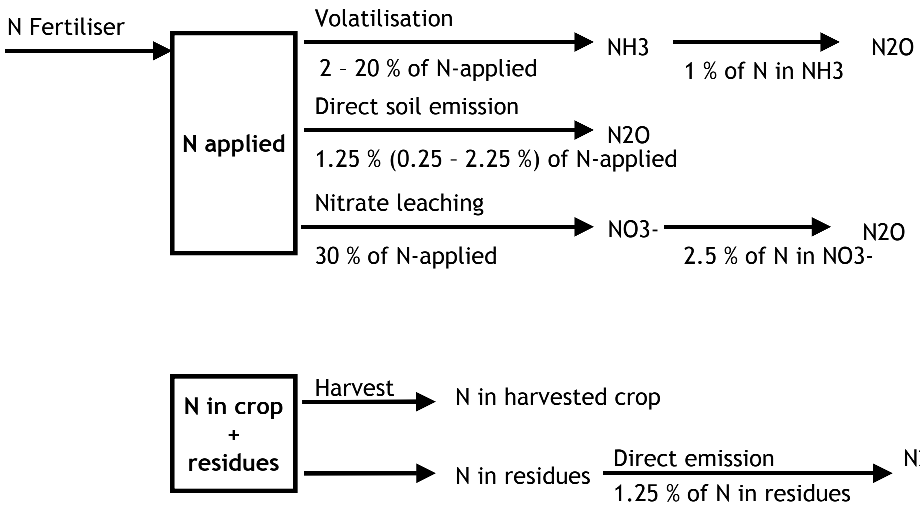

Figure Annex C-1. The N_2O emissions according to the IPCC method.

In the Dutch LCA [Hamelinck et al. 2005] a crop specific nitrogen balance is presented that deals more specifically with N_2O emissions from crop residues.

Other nutrient emission

In the case of phosphorus fertilisers it was assumed that 9% of the P surplus leaches to groundwater in the form of phosphate.

C.10 Nitrogen fertiliser production

Fertiliser production

The production of fertilisers demands much energy and generates considerable greenhouse gas emissions. It has been estimated that fertiliser production consumes about 1.2% of the worlds energy and is responsible for approximately 1.2% of the total GHG emissions [Wood et al. 2004]. Therefore, fertiliser production is an important component of this LCA.

Fertiliser emission factors vary widely depending on production technology. Wood and Cowie [2004] provide an overview of published GHG emission factors associated with the production of a range of nitrogen, phosphate and multi-nutrient fertilisers. The studies were generally coupled with energy LCA. They also remark that emission factors for similar fertiliser products differ markedly between reports, but that a lack of transparency limits the comparison between sources.

GHG emission from nitrogen fertiliser production

Key nitrogen fertilisers are:

- Ammonium nitrate (AN)
- Calcium ammonium nitrate (CAN)
- Urea
- Urea ammonium nitrate (UAN)

Ammonia is the primary input for the majority of nitrogen fertilisers. Along with N_2O emissions from subsequent nitric acid production, CO_2 emissions from ammonia production dominate GHG emissions from nitrogen fertiliser manufacture [Wood et al. 2004]. Ammonia is generally produced by the Haber-Bosch process where three volumes of hydrogen react with one volume of nitrogen over an iron catalyst. Nitrogen stems from air, and hydrogen (in Europe) generally from natural gas. The process is very energy demanding and CO_2 emissions range from 1.4 to 2.6 kg CO_2/kg N in NH_3 [Wood et al. 2004]

Weak nitric acid is used in the manufacturing of ammonium nitrate, calcium nitrate and potassium nitrate, which, in turn, are used either as straight fertilisers or mixed into compound fertilisers. Most weak nitric acid production is based on the Oswald process [Smit et al., 2001; [Wood et al. 2004]: Catalytic oxidation of ammonia with air into nitric oxide

- Oxidation of nitric oxide into nitrogen dioxide
- Absorption of nitrogen dioxide in water to produce nitric acid.

Nitrous oxide (N_2O), nitrogen monoxide (NO aka nitric oxide) and nitrogen dioxide (NO_2) are produced as unwanted by-products during catalytic oxidation of ammonia. IPCC currently believe that nitric acid production is the largest industrial source of N_2O [Wood et al. 2004]. The amount of N_2O emitted depends on combustion conditions, catalyst composition, burner design and emission abatement technology.

The N_2O emissions reported by Wood and Cowie [2004] range from 2.5 to 13.4 kg CO_2 equivalent/kg N (or 0.55 to 2.9 kg CO_2 equivalent/kg nitric acid, or 0.0018 to 0.0095 kg N_2O/kg nitric acid). The broad variation is attributed to the installation of emission abatement technologies. IPCC reports emission factors as high as 5.8 kg CO_2 equivalent/kg nitric acid.

6 Nitric acid plants in the Netherlands produce together 7010 tonne nitric acid per day and emit 54.1 – 59.1 tonne N_2O per day, this is 0.00807 kg N_2O/kg nitric acid [Smit et al. 2001], or about 2.5 kg CO_2 equivalent/kg nitric acid.

In both the reports of Wood and Cowie [2004] and that of Smit [2001] it is unclear what the concentration of this nitric acid is. We assume that emissions are expressed on pure HNO_3 basis.

IPCC applies default coefficients for nitric acid production facilities (see Table Annex C-8).

Table Annex C-8. Nitric acid production, default global coefficients [IPCC, 2001].

Technology	N_2O emission factor (kg N_2O /t HNO_3)
Atmospheric pressure plant	4 - 5
Medium pressure plant (< 6 bar)	6 - 8
High pressure plant (> 7 bar)	9
Abatement technology	N_2O abatement factor
Non-selective catalytic destruction	80 – 90%
Selective catalytic destruction[1)]	0

1) Under certain conditions, selective catalytic reduction can even result in an increase of N_2O emissions [IPCC, 2001].

Ammonium nitrate is produced by neutralising gaseous ammonia with aqueous nitric acid. The solution is evaporated and then formed into solid fertiliser by prilling or granulation. Before solidification, the solution may be mixed with dolomite or limestone to make calcium ammonium nitrate [Wood et al. 2004].

The majority of the emissions associated with production of AN or CAN are CO_2 from the ammonia synthesis and N_2O from nitric acid production. Emissions arising from processing of intermediate products into final products are of minor importance [Wood et al. 2004].. The emissions reported by Wood and Cowie [2004] are summarised in Table Annex C-9.

Table Annex C-9. Greenhouse gas emissions for ammonium nitrate (AN) and calcium ammonium nitrate (CAN), as reported in several studies [Wood et al. 2004].

	kg CO_2/kg N in product	kg N_2O/kg N in product	Total kg CO_2 equivalent/kg N in product
AN[1)]	1.5 – 2.8	0.013 – 0.017	3.0 – 7.1
CAN	2.6 – 3.2	0.013 – 0.020	3.0 – 9.6
Urea	0.9 – 4.0		0.9 – 4.0
UAN	1.3 – 3.4	0.0073 – 0.0075	2.0 – 5.7

1) Ammonium nitrate has chemical formula NH_4NO_3; nitrogen content is 35%.

2) Calcium ammonium nitrate is a mixture of ammonium nitrate with a minimum of 20% calcium carbonate. The nitrogen content is 25 – 28%.

Urea accounts for almost 50% of world nitrogen fertiliser production. It is synthesised by reacting ammonia and carbon dioxide at high pressure to form ammonium carbonate, which is subsequently dehydrated to form urea and water. Liquid urea-ammonium nitrate (UAN) is formed by mixing and cooling concentrated urea and ammonium nitrate solutions [Wood et al. 2004].

Emissions from urea production are dominated by CO_2 from ammonia production. UAN production entails significant N_2O from the nitric acid intermediate in ammonium nitrate synthesis. CO_2 from the production of ammonia is often used for the production of urea, but different interpretation leads to a broad range in Table Annex C-9.

N_2O abatement

Smit [2001] assessed the available technologies, and those under development, to reduce N_2O emission from nitric acid production. Direct decomposition of N_2O, either in the NH_3 combustion reactor or downstream the absorber, is the most cost efficient technique costing less than 1 €/tonne CO_2 avoided. These options cannot be applied to every nitric acid plant, depending on reactor space and temperature. Other technologies are selective catalytic reduction (SCR) and catalytic decomposition downstream the expander, which have a cost efficiency of typically 2 €/tonne CO_2 avoided [Smit et al. 2001].

Non-selective catalytic reduction (NSCR), a typical tail gas treatment in the USA and Canada, may reduce N_2O emissions by 80 – 90% [Wood et al. 2004]; [IPCC, 2001].

These technologies will only be applied when legislative or economic driving forces are introduced [Smit, 2001].

GHG emission from phosphate fertiliser production

Key phosphate fertilisers are:

- Single superphosphate (SSP)
- Triple superphosphate (TSP)
- Diammonium phosphate (DAP)
- Monoammonium phosphate (MAP)

The majority of phosphate fertilisers are based on phosphoric acid, which is produced by reacting sulphuric acid with naturally occurring phosphate rock. Ammonium phosphate fertilisers (MAP and DAP) are produced by reacting phosphoric acid with anhydrous ammonia. SSP is made by reacting ground phosphate rock with various concentrations of sulphuric acid, and TSP is produced by combining ground phosphate rock or limestone with low concentration phosphoric acid.

Emissions are dominated by CO_2, related to the consumption of fossil fuels in sulphuric acid production. The estimates in Multi-nutrient NPK fertilisers can be produced via a nitrophosphate route and a mixed acid rout, or alternatively by simply mixing dry fertilisers. Emissions differ per exact composition, process type and status of the technology, and range from 0.060 to 2.1 kg CO2 equivalent/kg product [Wood et al. 2004].

Table Annex C-10 assume that the majority of sulphur used is recovered from natural gas and fuel oil. The exothermic reaction to sulphuric acid may generate a net energy export, which explains the negative CO_2 emission in some studies.

GHG emission from NPK fertiliser production

Multi-nutrient NPK fertilisers can be produced via a nitrophosphate route and a mixed acid rout, or alternatively by simply mixing dry fertilisers. Emissions differ per exact composition, process type and status of the technology, and range from 0.060 to 2.1 kg CO_2 equivalent/kg product [Wood et al. 2004].

Table Annex C-10. Greenhouse gas emissions from phosphate fertiliser production as reported in several studies [Wood et al. 2004].

	Composition N:P:K:S	Total kg CO_2 equivalent/kg product
SSP	0:21:0:23	-0.050 – 0.22
TSP	0:48:0:0	-0.20 – 0.52
DAP	18:46:0:0	-0.070 – 0.87
MAP	11:52:0:0	-0.27 – 0.70

Assumptions for the present LCA

In the present LCA CAN is used as fertiliser for both wheat and rapeseed production. The data are taken from the Ecoinvent database for production processes in Europe. For the production of 1 kg "calcium ammonium nitrate as N" 0.608 kg ammonia and 2.25 kg nitric acid (50% solution) is required. 1 kg of this 50% solution is produced by 0.294 kg ammonia in 2 litre water. The resulting emission is 0.00839 kg N_2O/kg HNO_3.

This compares with the 0.00807 kg N_2O/kg nitric acid average for the Dutch facilities reported by Smit [2001], and is in the high range of the IPCC default coefficients (Table Annex C-8).

Annex D Conversion feedstock to biofuel

D.1 Pure plant oil from rapeseed; biodiesel from rapeseed oil; biodiesel from vegetable oil

Table Annex D-1. Rapeseed to biodiesel conversion [Elsayed et al. 2003, Annex B].

	Value applied
Drying from mc 15 → 9% [1)]	305 MJ/tonne dried oilseeds
Storage[2)]	11.6 kWh/tonne dried oilseeds
Solvent extraction[3)] Natural gas Electricity Hexane	 1790 MJ/tonne oil extracted 84 kWh_e/tonne oil extracted 2.5 kg/tonne oil extracted
Yields	0.4 kg oil/kg dried oilseeds 0.6 kg rape meal/kg dried oilseeds
Allocation	72.42% to crude rapeseed oil 27.68% to rape meal (animal feed)
Refining[4)] Electricity Natural gas Heavy Fuel oil Light Fuel oil Phosphoric acid Smectite (not considered)	 3.1 kWhe/tonne refined rapeseed oil 178 MJ/tonne refined rapeseed oil 20 MJ/tonne refined rapeseed oil 152 MJ/tonne refined rapeseed oil 1 kg/tonne refined rapeseed oil 6 kg/tonne refined rapeseed oil.
Yields:	0.973 kg oil refined/kg oil extracted
Esterification[5)] Electricity Natural gas Heavy fuel oil Light fuel oil Caustic soda (50% concentration) Methanol	 23 kWh/tonne biodiesel 1402 MJ/tonne biodiesel 161 MJ/tonne biodiesel 161 MJ/tonne biodiesel 12 kg/tonne biodiesel 109 kg/tonne biodiesel
Yields	0.797 kg biodiesel/kg refined oil 0.095 kg glycerine/kg refined oil
Allocation esterification section	87.44% to biodiesel 12.56% to crude glycerine
Overall allocation[5)]	61.1% to biodiesel 30.1% to animal feed 8.5% to crude glycerine

1) This corresponds with 4.32 GJ/tonne water evaporated, which sounds inefficient, it should rather be 2.5 GJ/tonne water evaporated [Pierik, 1995]. The SPA considers rather 12 to 8% with the same energy per tonne water.

2) Mainly cooling

3) Solvent extraction consumes steam, generated from natural gas 716 kg steam /tonne crude rapeseed oil, and 2.5 MJ natural gas/kg steam [Elsayed, 2003]. Electricity 84 kWhe/tonne crude rapeseed oil extracted, hexane 2.5 kg/tonne of crude rapeseed oil extracted.

4) 3.1 kWhe/tonne refined rapeseed oil. Natural gas 178 MJ/tonne refined rapeseed oil , heavy fuel oil 20 MJ/tonne refined rapeseed oil, light fuel oil 152 MJ/tonne refined rapeseed oil, phosphoric acid consumption 1 kg/tonne refined rapeseed oil and smectite 6 kg/tonne refined rapeseed oil.

5) Biodiesel 383 €/tonne, animal feed 120 €/tonne, crude glycerine 550 €/tonne, crude bio-oil 460 €/tonne [Elsayed, 2003]. The overall allocation is the part of the rapeseed impact burden that can be allocated to the three products separately.

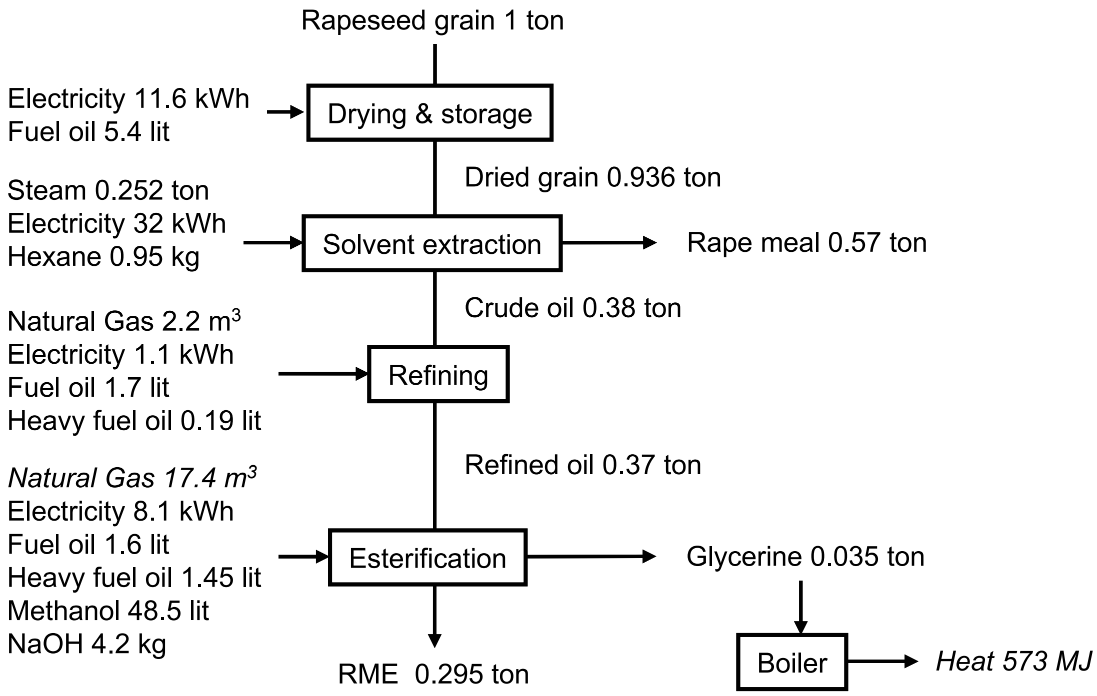

Figure Annex D-2. Rapeseed to biodiesel conversion - flow chart [Elsayed et al. 2003, Annex B].

D.2 Bioethanol from wheat

Table Annex D-2. Wheat to ethanol conversion [Elsayed et al. 2003, Annex R].

	Value applied
Drying from mc 16 → 3% Fuel oil	661 MJ/tonne fresh grains
Storage[1)] Electricity	11.6 kWh/tonne dried grains
Milling Electricity	12.3 kWh/tonne dried grains
Yields	34.6 kg Bran/ tonne fresh grains 831 kg course powder flour/tonne fresh grains
Allocation	99.9% to course powder flour 0.1% to bran
Hydrolysis, fermentation, distillation Natural gas	8145 MJ/tonne ethanol (94%)
Drying stillage Natural gas	5722 MJ/tonne animal feed
Yields	431 kg animal feed/tonne fresh grains
Allocation	76.4% to ethanol 23.6% to animal feed
Dehydration Natural gas	47 MJ/tonne ethanol
Yields	360 l ethanol/tonne fresh grains[3)]
Overall allocation[2)]	76.2% to ethanol 23.7% to animal feed 0.1% to bran

1) Mainly cooling energy.
2) Ethanol 555 €/tonne, animal feed 114 €/tonne, bran 14 €/tonne [Elsayed, 2003], course powder flour 433 €/tonne [Elsayed, 2003].
3) Range 346 – 385 l/tonne in Fact-finding study [GAVE, 2003].

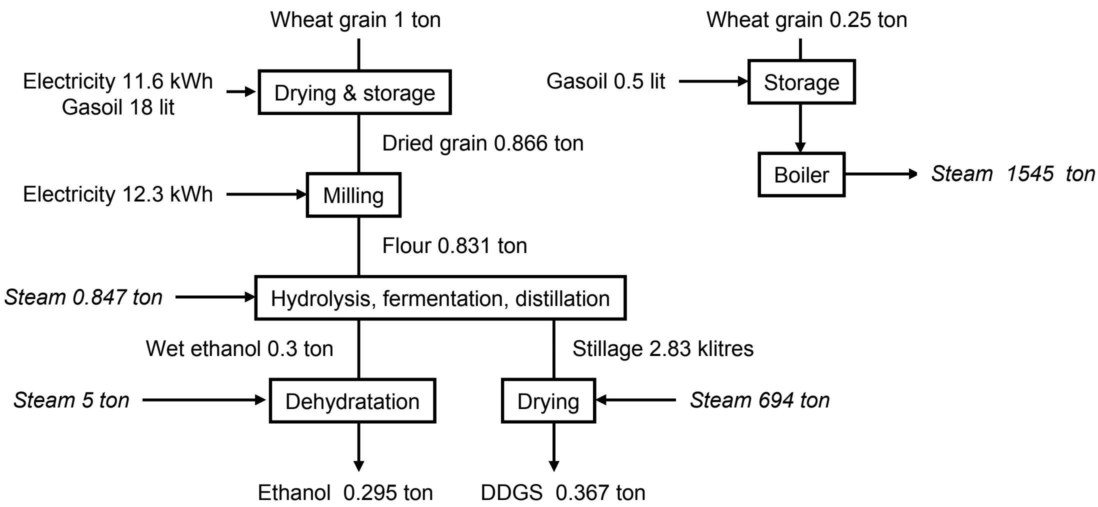

Figure Annex D-3. Wheat to ethanol conversion - flow chart [Elsayed et al. 2003, Annex R].

D.3 Bioethanol from sugar beet

Table Annex D-3. Sugar beet to ethanol conversion [Elsayed et al. 2003, Annex Q].

	Value applied
Loading, preparation, earth handling, water effluent treatment Electricity	3.7 kWh/tonne soiled sugar beet
Storage Electricity	0.35 kWh/tonne clean sugar beet
Shredding Electricity	0.6 kWh/tonne clean sugar beet
Diffusion Electricity Steam	1.6 kWh/tonne clean sugar beet 64 MJ/tonne clean sugar beet
Pulp drying	N/A
Yields	1.033 tonne raw juice/tonne soiled beets 0.051 tonne animal feed/tonne soiled beets
Allocation[1)]	76.4% to raw juice 23.6% to pulp
Pasteurisation, Steam	44 MJ/tonne clean sugar beet
Fermentation Steam	25.5 kWh/tonne pure bioethanol
Distillation Electricity Steam	40 kWh/tonne pure bioethanol 5900 MJ/tonne pure bioethanol

1) Ethanol 555 €/tonne, animal feed 114 €/tonne, pulp with 97% moisture has an effective price of 5.16 €/tonne [Elsayed, 2003]; otherwise derive price from actual sugar beet pulp nut price. Raw juice (15% solids, 88% sugar) has an effective price of 25.2 €/tonne, derived from thick juice with a 67% solids and 92.5% sugar [Elsayed, 2003].

3) Range 346 – 385 l/tonne in Fact-finding study [GAVE, 2003].

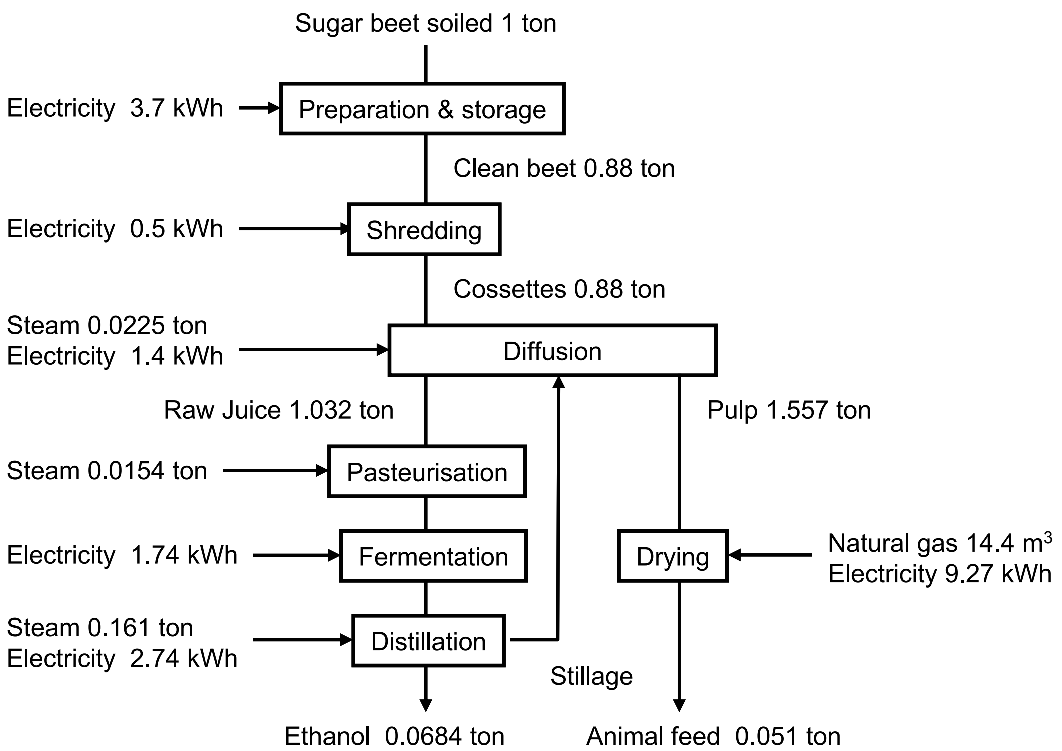

Figure Annex D-4. Sugar beet to ethanol conversion - flow chart [Elsayed et al. 2003, Annex Q].

D.4 Bioethanol from wood

Table Annex D-4. Bioethanol from wood

	Value applied	
Pretreatment		
Electricity	6.7 kWhe/tonne ethanol	Lynd et al., 1996
Steam 3.5 bar	0.7 tonne/tonne ethanol	Lynd et al., 1996
Steam 10.5 bar	0.33 tonne/tonne ethanol	Lynd et al., 1996
Fuel oil	7.9 lit/tonne dry wood	CONCAWE, 2003
Hydrolysis		CONCAWE, 2003
H_2SO_4	391 MJ/tonne ethanol 19.6 kg CO_2/tonne ethanol	
NH_3	3197 MJ/tonne ethanol 185 kg CO_2/tonne ethanol	
$(NH_4)_2SO_4$	284 MJ/tonne ethanol 16.1 kg CO_2/tonne ethanol	
Fermentation		
Electricity	0.6 kWh/tonne clean sugar beet	Lynd et al., 1996
Steam 3.5 bar	1.3 tonne/tonne ethanol	Lynd et al., 1996
Antifoam	193 MJp/tonne ethanol 0.8 kg CO_2/tonne ethanol	CONCAWE, 2003
Corn steep liquor	180 MJp/tonne ethanol 0.8 kg CO_2/tonne ethanol	CONCAWE, 2003
CaO		CONCAWE, 2003
Purification		
Electricity	103 kWhe/tonne ethanol	Lynd et al., 1996
Combined heat and power plant	790 kWhe/tonne dry wood 652 ton steam/tonne dry wood	Reith et al., 2002
Yield	0.28 tonne ethanol/tonne dry wood 750 kWhe/tonne dry wood	Reith et al., 2002

SPA in Chapter 6 uses the data from the Table Annex A-1. For the greenhouse gas balance calculations in Chapter 5, the electricity is assumed to be produced from wood at 45% HHV efficiency. If the amount of wood required to produce the 2.7 GJ electricity is subtracted from the feedstock, the conversion of wood to ethanol becomes 0.404 tonne/tonne.

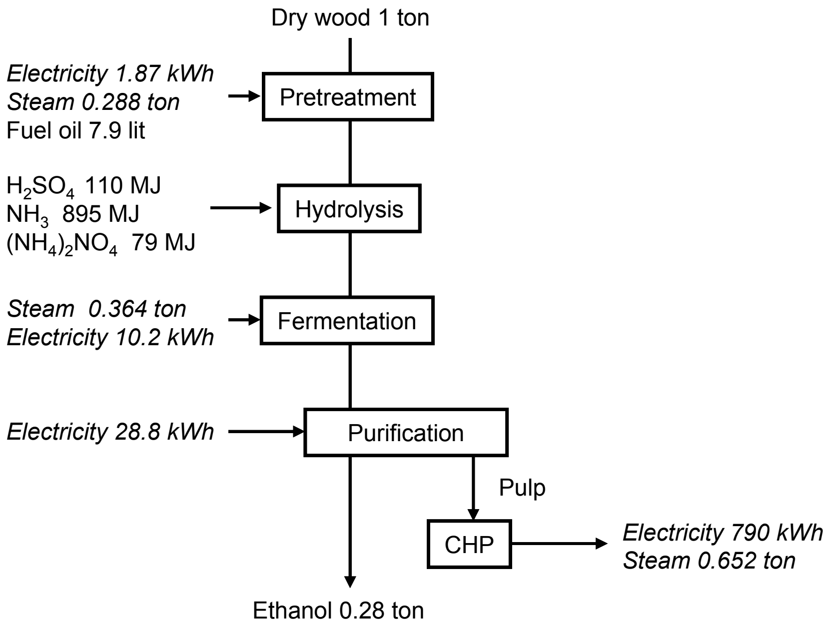

Figure Annex D-5. Wood to ethanol conversion - flow chart

D.5 Biodiesel from wood (FT aka BTL)

Table Annex D-6. Biodiesel from wood or Fischer-Tropsch Diesel [Hamelinck et al., 2003]

	Value applied
Pretreatment	
Gasification Electricity	635.5 kWhe/tonne ethanol
Gas cleaning & processing Dolomite	2.46 tonne/tonne ethanol 1427 MJp/tonne ethanol 50.7 kg CO_2/tonne ethanol
Auxiliaries Electricity	1282 kWhe/tonne ethanol
Combined cycle plant	7705 kWhe/tonne ethanol
Yield	0.122 tonne ethanol/tonne dry wood 0.018 tonne light fuel/tonne dry wood[1)]

1) The light fraction is considered to replace the diesel for heating. Assuming 80% efficiency and a heating value of 45 MJLHV/kg this means that about 179 kWh heat/tonne dry wood could be produced. The overall efficiency that can be allocated to FT diesel production is about 0.196 tonne diesel/tonne wood, or about 47% on HHV basis.

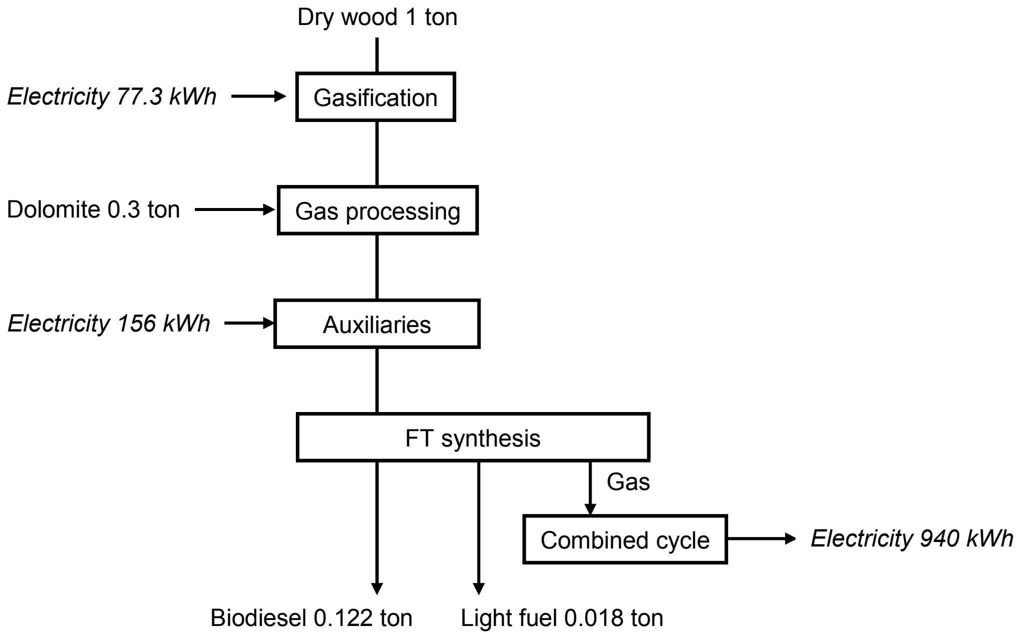

Figure Annex D-6. Wood to FT diesel conversion - flow chart

D.6 ETBE

Figure D-6 summarises the data for the step from ethanol to ETBE. Data are obtained from Kadam et al [1999].

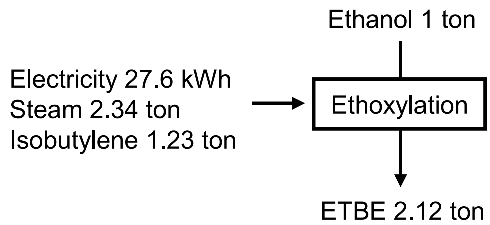

Figure Annex D-6. Ethanol to ETBE - flow chart

D.7 Heat and/or power from wood

The data for the considered heat and/or power production cases are be summarised in Table D-7. Data are taken from [Novak et al., 2005]

Table Annex D-7. Assumed data for heat and/or power from wood [Novak et al., 2005]

Case	Power range	power range	heat efficiency	electric efficiency	total efficiency	Investment cost	O&M
	total MW_{th} in	MW_e	%	%	%	Euro/kW_{th} (total in)	% inv.
Hot water boiler	0.1-10	n.appl.	85	n.appl.	85	200	4
Fixed bed gasifier	2.4	0.6	55	25	80	700	4
Organic Rankine Cycle	7.3	1.1	80	15	95	600	3
Medium size steam plant	10-100	1-30	0	20	20	500	4.5
Coal (co)combustion	100[1)]	35[1)]	0	35	35	500	4.5
BIC/CC	>25	>10	n.appl.	~45	~45	1200	4

D.8 Energy, CO_2 and costs associated to plant construction

In the SPA detailed in Chapter 6, energies, CO_2 and costs associated to the considered conversion plants have been included as much as possible. The data used are summarised in Table D-8. Most of the data are taken from Elsayed et al. [2003] unless specified otherwise. The CO_2 emissions are estimated from the energy at an average emission coefficient of 70g/MJ.

The first column of the Table shows euros of investment cost, expressed per ton of resource entering the system (wheat, wood, etc..). This first column is considered to be relatively reliable, as far as such data can be.

The second column allows for the calculation of the energy requirements of the plant construction. Some of these have been extrapolated from others, as again indicated in the Table. Abnormal high values of 0.56 and 1.11 euro/MJ were found respectively for wood for ethanol and wood for Fischer-Tropsch, which are the two cases which are yet very uncertain. In both cases the energy requirements specified are probably underestimated, because costs as high as fifty to hundred times the investment costs are highly improbable. For all ethanol and RME cases the energetic cost has been limited tentatively to 0.2 euro/MJ. The heat and power cases show much lower energetic costs, and the gas boiler case has been extrapolated from the others. Only the FBG case shows a high energetic cost, probably because of the gasification and cleaning systems (as is for the FT case).

The last column finally represents the assumed yearly O&M costs, in terms of percentage of the total investment cost.

Table D-9 gives the additional assumptions to make the cost calculations. The annuities are calculated according to [Hamelinck, 2004a] :

$$A = \frac{IR}{1 - \frac{1}{(1+IR)^{TE}}} INV \left(1 - \frac{1}{(1+IR)^{TE}} \frac{TT - TE}{TT} \right)$$

Where

$$A = \text{Annuity}(\text{euro/year})$$
$$IR = \text{interest rate}$$
$$INV = \text{Total investment}(\text{euro})$$
$$TL = \text{Technical Lifetime}$$
$$EL = \text{Economic Lifetime}$$

Table Annex D-8. Energy and cost requirements for conversion plants [Elsayed et al., 2003, unless otherwise specified]

	euro/ton resource	euro/MJ	% O.M.
wheat for ethanol [3)]	186	0.19	3.5
wheat for ethanol, straw burnt [3)]	297	0.19	3.5
wheat for ETBE [4)]	530	0.13	3.5
wood for ethanol [1,5)]	512	0.20	3.5
sugar beet for ethanol	39	0.17	3.5
Rapeseed for PPO [2,8)]	420	0.03	1
Rapeseed for RME [7)]	162	0.14	3.5
Rapeseed for RME, glyc. Burnt [7)]	216	0.14	3.5
wood for Fischer-Tropsch [1,6)]	445	1.11	4
wood for heat	300	0.036	3.5
natural gas for heat [2)]	469	0.036	4
wood for ORC CHP	750	0.029	4
wood for FBG CHP	1050	0.19	4
wood for co-combustion	469	0.04	4.5
wood for medium steam plant	375	0.056	4.5

1) Limited to 0.2
2) Estimation
3) Vandevoorde 2005; Elsayed et al., 2003
4) Gnansounou et al., 2000; Vandevoorde 2005; Elsayed et al., 2003;
5) Reith et al. 2002, Elsayed et al., 2003
6) Hamelinck et al., 2003; Elsayed et al., 2003
7) www.havegent.be (24/05/2005); Elsayed et al., 2003
8) Jossart et al. 2005

Table Annex D-9. Data for cost plant calculations [Elsayed et al., 2003]

Energetic maintenance cost	2.5%	MJ/MJ
Economic lifetime	15	years
Technical lifetime	25	years
Interest rate	10%	-

D.9 Emissions from stationary combustion

Table Annex D-14. Emissions from stationary combustion (mg/MJ input)

	NO_x	SO_x	CO	PM
Natural gas[1)]	26.2	0	4.2	1.87
Fuel oil lowS	58.4	0	4.2	48.7
Straw	48.7	0	4.2	9.7

1) Offgas flow is 1282 kg/h at a gas use of 82 m^3_0/h and 31.68 MJ_{LHV}/m^3_0, or 494 kg/GJ gas input [Remeha, 2001]. Offgas flow is 24.7 tonne/h at 14.5 MW nominal, or 473 kg/GJ gas input [Viessmann 2001]. We assume 483 kg offgas/GJ gas input. Gas volume is about 1.29 kg/m^3. Emissions according to adapted BEES A [2005] (article 13.1f, 13.4d and 13.5c) are: SO_x < 35 mg/m^3, NO_x 70 mg/m^3 and particles 5 mg/m^3. Carbon monoxide is assumed 15 mg/kWh_{th} [Viessmann 2001]. SO_x from natural gas is assumed to be 0.

2) The offgas volume for fuel oil is larger than that of natural gas: it contains 13% CO_2 instead of 10%, which requires 30% more air. We assume that the offgas flow is 628 kg/GJ fuel input. Emissions according to BEES A (Article 12.1c2, 12.4d and 12.5a) are: SO_x 850 mg/m^3, NO_x 120 mg/m^3 and particles 100 mg/m^3. We assume that the SO_x emission from low sulphur fuel oil is negligible. CO emission is assumed the same as for natural gas.

3) The offgas volume for straw is assumed to be the same as for fuel oil: 628 kg/GJ input. Emissions according to adapted BEES A [2005] (Article 11.1c2, 11.3c4 and 11.4b) are: SO_x 200 mg/m^3, NO_x 100 mg/m^3 and particles 20 mg/m^3. We assume that the SO_x emission from straw is negligible. CO emission is assumed the same as for natural gas.

Annex E End use

The end-use of the biofuels is as blends in weighted averages of the Dutch car park. Ethanol and ETBE will be used in passenger cars only, while biodiesel is to be used in both passenger cars and heavy-duty vehicles. Since it is not possible to estimate a distance average, the average is based on the number of cars.

The scope of the LCA is the year 2008. The exact car park composition of that year is not yet known. To estimate this composition, the distribution of passenger car ages on January 1st 2004 [CBS, 2004] has been translated four years. No information was available on the age of heavy-duty vehicles. Therefore, the age distribution has been estimated to be the same as for passenger cars on diesel.

Table Annex E-1. Estimated car park composition at January 1st, 2008, divided over Euro types.

		Gasoline	Diesel
Passenger vehicles			
1904 - 1991	pre Euro	13.27%	5.18%
1992 - 1995	Euro 1	10.88%	4.79%
1996 - 1999	Euro 2	21.84%	11.52%
2000 - 2004	Euro 3	34.53%	46.29%
2005 - 2007	Euro 4	19.48%	32.23%
Heavy duty vehicles			Diesel
1904 - 1991	pre Euro		5.18%
1992 - 1996	Euro I		7.12%
1997 - 1999	Euro II		9.18%
2000 - 2004	Euro III		46.29%
2005 - 2007	Euro IV		32.23%

Ethanol vs gasoline

In the Fact-finding study [Van den Broek et al. 2003], the vehicle efficiency for ethanol and gasoline was assumed to be 2.59 MJ_{LHV}/km.

The IEA [Van Walwijk et al. 1999] compared vehicular emissions from ethanol with gasoline (see Table Annex E 2). NO_x and CO emissions were found to decrease.

Table Annex E-2. Vehicular emissions (g/km) (Van Walwijk et al. 1999).

	NO_x	CO	VOC	Pm	CO_2
Gasoline	0.3 (0.2 – 0.4)	4 (2.1 – 6)	0.45 (0.1 – 0.8)	-	219 (181 – 256)
Ethanol	0.10 (33%)	1.6 (40%)	0.45 (100%)	-	n/a

Baert [2005] concludes that for these fuels available engine efficiency and emission data are very difficult to compare. It is not possible to conclude whether ethanol leads to different emissions of NO_x , CO and VOC. Emissions are expected to be the same because all vehicles have a three way catalyst and the European test cycle does not include the effects of cold start. The efficiency of cars on ethanol will not be higher than those on gasoline, unless the cars would be recalibrated for optimum results on E5.

The emission of sulphur from future gasoline is so low that the sulphur in the lubricant becomes likewise important. The small sulphur emission from gasoline and ethanol will be very similar and is therefore not taken into account (deducted from both the biofuel and the reference case).

Combination of the passenger car park composition of Table Annex E-3 with emission limits for Euro 1 – 4 vehicles gives average emissions and fuel efficiency to be used in the present life cycle assessment.

Table Annex E-3. Emissions and fuel efficiency of passenger cars on gasoline or ethanol averaged over the market share Euro 1-4 vehicles.

	Year introduction	Share (%)	Emission (g/km)				fuel efficiency (MJ/km)
			CO	HC	NO_x	PM	
Euro 1	1992	24.15%	2.72	0.485[1]	0.485[1]	0.14	2.59[2]
Euro 2	1996	21.84%	2.2	0.25[3]	0.25[3]		2.46[4]
Euro 3	2000	34.53%	2.3	0.2	0.15		2.34[4]
Euro 4	2005	19.48%	1	0.1	0.08		2.21[4]
Average			**2.13**	**0.26**	**0.24**	**0.03**	**2.40**

1) The total of HC and NO_x is 0.97 g/km.
2) From Ecofys' fact-finding study [Van den Broek et al. 2003].
3) The total of HC and NO_x is 0.5 g/km.
4) Assuming "normal" gasoline, new fleet data [Baert, 2005].

Biodiesel vs diesel

In the Fact-finding study [Van den Broek et al. 2003], the vehicle efficiency for biodiesel and diesel was assumed to be 2.08 MJLHV/km.

The IEA [Van Walwijk et al. 1999] compared vehicular emissions from biodiesel with diesel (see Table Annex E-4). NO_x was found to increase, while other emissions decrease.

Table Annex E-4. Vehicular emissions (g/km) [Van Walwijk et al. 1999].

	NO_x	CO	VOC	Pm	CO_2
Diesel	0.92 (0.6 – 1.2)	0.81 (0.4-1.2)	0.27 (0.06 - 0.5)	0.2	170 (139 – 197)
Biodiesel	1.10 (120%)	0.73 (90%)	0.23 (88%)	0.17 (87%)	n/a

Baert [2005] that adding biodiesel will result in a change in somewhat higher PM and NO_x emissions. This could be counteracted by recalibration of the engine, though that would typically result in a loss of efficiency. With B5 the increase is expected to be such that the diesel engine emissions are still within its emission limitations. It is not likely that a recalibration for emissions reasons would be necessary. There is little or no effect on energy consumption.

Combination of the passenger car park composition of Table Annex E 5 with emission limits for Euro 1 – 4 and Euro I – IV vehicles gives average emissions and fuel efficiency to be used in the present life cycle assessment.

Table Annex E-5. Emissions and fuel efficiency of passenger cars on diesel or biodiesel averaged over the market share Euro 1-4 vehicles.

	Year introduction	Share (%)	Emission (g/km)				fuel efficiency (MJ/km)
			CO	**HC**	NO_x	**PM**	
Euro 1	1992	9.97%	2.72	0.485[1)]	0.485[1)]	0.14	2.08
Euro 2	1996	11.52%	2.2	0.25[3)]	0.25[3)]		2.34
Euro 3	2000	46.29%	2.3	0.2	0.15		2.13
Euro 4	2005	32.23%	1	0.1	0.08		2.02
Euro I	1992	12.31%[1)]	4.5	1.1	8	0.35	8.33
Euro II	1997	9.18%[1)]	4	1.1	7	0.15	8.37
Euro III	2000	46.29%[1)]	2.1	0.66	5	0.1	8.81
Euro IV	2005	32.23%[1)]	1.5	0.46	3.5	0.02	8.24
Euro V	2008		1.5	0.46	2	0.02	8.24
Average diesel cars 2008[2)]			**1**	**0.31**	**0.75**	**0.06**	**2.76**
Euro 1	1992	9.97%	2.45	0.41	0.53	0.15	2.08
Euro 2	1996	11.52%	0.9	0.34	0.44	0.099	2.34
Euro 3	2000	46.29%	0.58	0.24	0.31	0.055	2.13
Euro 4	2005	32.23%	0.45	0.13	0.17	0.013	2.02
Euro I	1992	12.31%[1)]	4.05	0.94	8.8	0.39	8.33
Euro II	1997	9.18%[1)]	3.6	9.34	7.7	0.17	8.37
Euro III	2000	46.29%[1)]	1.89	0.56	5.5	0.11	8.81
Euro IV	2005	32.23%[1)]	1.35	0.39	3.85	0.02	8.24
Euro V	2008		1.35	0.39	2.2	0.01	8.24
Average biodiesel cars 2008[2)]			**0.9**	**0.27**	**0.83**	**0.06**	**2.76**

1) The age composition of the truck car park is unknown, the same distribution as for the passenger car park has been assumed, although in reality, the truck car park is expected to be somewhat younger.

2) Averaged between 9 passenger car kilometres plus 1 truck kilometre.

Annex F Normalisation levels

Normalisation levels for Belgium were not found. Normalization levels for Dutch territory and for the West European Territory are given by Blonk et al. In the present study, the normalisation levels for West-European territory are applied.

Table Annex F-1. Normalisation figures for the Dutch territory (uncertainty is indicated by S-small, M-medium, C-Considerable), and West-European territory.

CML class	Unit	Dutch Territory around 1993 / 1994	West European territory 1990-1994
Enhancement greenhouse effect	kg CO_2-eq/yr	2,1E+11 S	4,2E+12
Depletion ozone layer	kg CFC11eq/yr	4,4E+06 M	5,6E+07
Photochemical smog formation	kg ethane-eq/yr	1,9E+08 M	6,3E+09
Acidification	kg SO_2eq/yr	9,2E+08 S	3,4E+10
Nutrification	kg PO_4eq/yr	1,1E+09 S	8,6-23E+09
Human toxicity	kg HC eq/yr	8,8E+08 C	3,9E+10
Aquatic eco-toxicity	M3 ECA/yr	8,9E+12 C	4,4E+14
Terrestric eco-toxicity low	kg ECT/yr	1,2E+13 C	2,3E+14
Terrestric eco-toxicity high	kg ECT/yr	1,4E+14 C	2,5E+16
Abiotic depletion	kg/yr	6,6E-03 S	pm
Energy use Low Heating Value	MJ/yr	2,9E+12 S	5,8E+13
Energy use High Heating Value	MJ/yr	3,1E+12 S	6,1E+13
Solid waste to be dumped	kg/yr	8,8E+09 S	9,7-54E+10

Annex G Basic methodology of input-output analysis

G.1 Macro-economic modelling

The basic principles of the economic modelling methodology are as follows:

- Assessment of the "with and without" cases. The macro-economic analysis of the introduction of a new product (the biofuel) and the related industry is best based on a *with/without* basis. The economic impact of implementing the change (e.g. by certain government measures) needs to be compared with the economic impact of not implementing this change. Often such an analysis is done on a *before/after* basis (comparing of the present situation with a certain future situation). This does however not fully reflect the fact that the business as usual scenario (in this case using 100% gasoline derived from fossil fuels) may also change in the future, because measures regarding energy efficiency improvement that will be undertaken anyway in the transport sector.
- Combining efficiency with accuracy. Full scale dynamic macro-economic modelling (e.g. by general equilibrium models) will require the use of rather complex and expensive models, although their results will generally model reality relatively accurately. Simple Input-Output models, combined with micro economic analysis of the product chain under consideration, are relatively time efficient to undertake. Although they are less reliable in terms of results, they can still provide a first order estimate of the macro-economic impacts.

G.2 The impact of an individual project (or product) on GDP and employment

The total cost (c) of a product can be split into three segments:

1. value added,
2. intermediate expenditures in the productive sector of the economy and
3. imports (see "round 0" in Figure Annex G-7).

Value added consists of all types of income for the various economic actors in society, such as salaries (income from labour), interest (income from capital), land rent, profit (income from entrepreneurship) and taxes minus subsidies (government income). The total gross value added in an economy (which includes depreciation) adds up to the GDP. Therefore a project's contribution to the GDP can be represented by the amount of value added in its cost.
In turn, the intermediate expenditures can be subdivided into the same three components, and so on (see "round 1" and further in Figure Annex G-7). Finally, the cost can be divided into imports (direct and indirect) and value added (direct and indirect).
The split into segments in round 0 in Figure Annex G-7 can be derived directly from the calculation of the cost. Using the standard input-output method it is possible to come directly from the cost breakdown of round 0 to that of round n. In the section below, this standard IO

method is discussed in more detail, after presenting the normal structure of the standard input-output table.
Employment creation can be included as a non-monetary variable that is important in view of the macro-economic objectives.

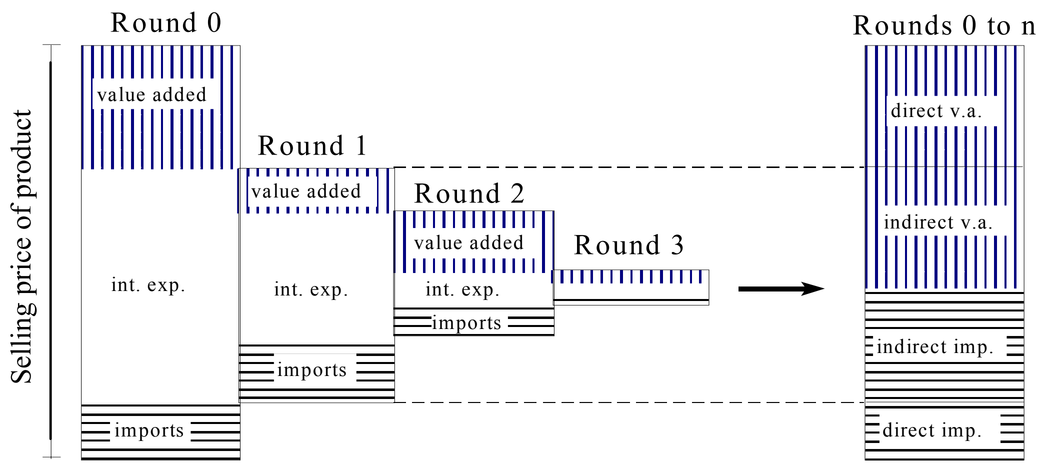

Figure Annex G-7. Product Cost Segmentation.

Figure Annex G-7 shows the division of the cost into the segments of import, intermediate expenditures and value added. (In the figure: *int. exp.* means intermediate expenditure, *v.a.* means value added and *imp*. means import).

G.3 The standard input-output table

The starting point for the standard input-output method is the input-output transaction table shown in Equation (4), which is available as standard statistical information for most countries in the world.[1]
For this study, the Belgium Input-Output table was supplied by the Federal Planning Bureau [www.plan.fgov.be].
The elements z_{ij} form the intermediate (inter-industry) section (Z matrix), representing the demand of sector j for products from sector i.
The final demand for products of sector i is represented by y_i, m_i indicates the imports by sector i and x_i is its total production. The production factors (w_i) consist of wages (for the production factor labour), rent (for land), interest payment (for capital) and profit (for entrepreneurship). Government income is represented by g_i, representing taxes minus subsidies.
Because demand has to equal supply, IO must meet:

$$\forall i: \; x_i = \sum_{j=1}^{n} z_{ij} + y_i = \sum_{j=1}^{n} z_{ji} + w_i + g_i + m_i \qquad (1)$$

The value added created by sector i can be calculated as:

$$v_i = w_i + g_i \qquad (2)$$

[1] In this description, capital letters represent matrices (including vectors) and lower case letters are scalars

This value added is called the gross value added if depreciation is included in the profit (gross profit) and is the net value added if the profit is a net profit (without depreciation). The sum of the gross value added of all n sectors in the economy gives the gross domestic product of a country:

$$GDP = \sum_{i=1}^{n} (w_i + g_i) \tag{3}$$

$$\mathbf{IO} = \left[\begin{array}{ccccc|cc}
z_{11} & z_{12} & z_{13} & \cdots & z_{1n} & y_1 & x_1 \\
z_{21} & z_{22} & z_{23} & \cdots & z_{2n} & y_2 & x_2 \\
z_{31} & z_{32} & z_{33} & \cdots & z_{3n} & y_3 & x_3 \\
\vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots \\
z_{n1} & z_{n2} & z_{n3} & \cdots & z_{nn} & y_n & x_n \\
\hline
w_1 & w_2 & w_3 & \cdots & w_n & & \\
g_1 & g_2 & g_3 & \cdots & g_n & & \\
m_1 & m_2 & m_3 & \cdots & m_n & & \\
\hline
x_1 & x_2 & x_3 & \cdots & x_n & &
\end{array}\right] \tag{4}$$

G.4 The standard input-output method

The aim of the standard input-output method in the application under consideration is to split the cost of a product (or project) into (direct and indirect) value added and (direct and indirect) imports, or in other words: to come from round 0 to round n of Figure Annex G 7 The assumption is made that the elements z_{ij} in the intermediate part of the IO matrix are linear with the total production of commodity j:

$$z_{ij} = a_{ij} x_j \tag{5}$$

In this way it is possible to define a normalised A matrix, called the technological matrix, with the element a_{ij}

$$\forall_{i,j} : \; a_{ij} = \frac{z_{ij}}{x_j} \tag{6}$$

In the same way it is possible to normalise (subscript "nr") the value added and import parts of the IO matrix.

$$\forall_i : \; w_{nr,i} = \frac{w_i}{x_i} ; \; g_{nr,i} = \frac{g_i}{x_i} ; \; m_{nr,i} = \frac{m_i}{x_i} \tag{7}$$

Figure Annex G 8 shows the structure of this normalised matrix and is a schematic representation of the economic system analysed (a, left-hand side) and the technological matrix and its normalised value added and import vectors (b, right-hand side). The arrows represent the flow of products.

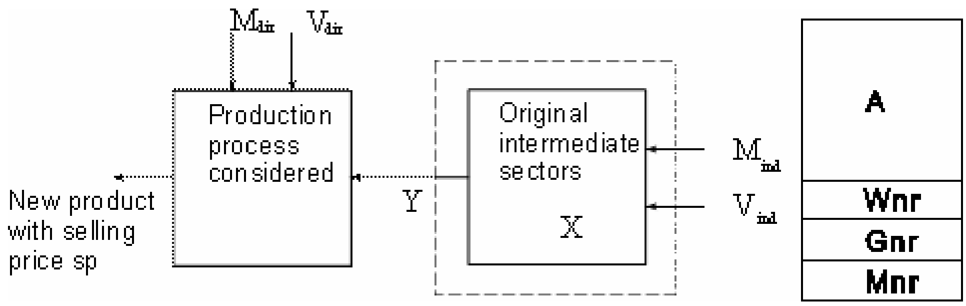

Figure Annex G-8. Schematic of the economic SYSTEM

The first part of Equation (1) can now be rewritten in matrix terms:

$$X = AX + Y \qquad (8)$$

or

$$(I - A)\, X = Y \qquad (9)$$

where I is the unit matrix. Assuming the inverse of (I-A) exists, multiply both sides by it:

$$(I - A)^{-1} (I - A)\, X = (I - A)^{-1}\, Y \qquad (10)$$

leading to:

$$X = (I - A)^{-1}\, Y \qquad (11)$$

The term $(I\text{-}A)^{-1}$ is called the Leontief inverse. Under the assumption that the average values of the A matrix are also representative for the marginal variation of vector X as a result of a marginal variation in vector Y, then:

$$\Delta X = (I - A)^{-1}\, \Delta Y \qquad (12)$$

In turn, the marginal variation in X has repercussions on the value added and the imports in the economy. The marginal (indirect) variation in imports and value added can now be calculated as:

$$\begin{aligned} \Delta m_{ind} &= M_{nr}\, \Delta X \\ \Delta v_{ind} &= \Delta W + \Delta G = (W_{nr} + G_{nr})\, \Delta X \end{aligned} \qquad (13)$$

G.5 Application of the standard IO method to new products

In the application of the standard IO method it is assumed that there is an additional demand for the product (e.g. additional demand for bioethanol) whose macro-economic impact needs to be assessed. Therefore, the production process for this product (e.g. production of bioethanol from biomass) is not yet included in the standard IO table and the direct (round 0) demand for inputs from the existing intermediate sectors (e.g. fertilisers, tractors or diesel) can thus be considered to be exogenous. Therefore, this direct demand of the new production process can be represented as an additional final demand vector ΔY, which will cause an additional production ΔX of the existing productive sectors.

In order to calculate the impact of a certain project or product on the gross domestic product, the cost (c) has to be broken down into direct value added, v_{dir} (=w_{dir}+g_{dir}), direct import, m_{dir}, and direct intermediate expenditures, ine_{dir} (round 0 of Figure Annex G-7). These direct intermediate inputs have to be converted into a (n x 1) ΔY vector, which means that for each separate cost item it has to be decided in what sector of the national economy it is produced (Equation 14).

$$c = v_{dir} + m_{dir} + ine_{dir} = v_{dir} + m_{dir} + \sum_{i=1}^{n} \Delta y_i \qquad (14)$$

With this ΔY vector, representing the first order (round) of the demand for intermediate products for the project under consideration, the total resulting additional production ΔX in all sectors in the economy can be derived from Equation (12) and the indirect marginal induced imports and value added (Δm_{ind} and Δv_{ind}) from Equation (13). The total value added and import part of the cost can than be calculated as:

$$\begin{aligned} v &= v_{dir} + \Delta v_{ind} = v_{dir} + (W_{nr} + G_{nr})\,\Delta X \\ m &= m_{dir} + \Delta m_{ind} = m_{dir} + M_{nr}\,\Delta X \end{aligned} \qquad (15)$$

By definition, the sum of these two items equals the cost (c) of the product considered:

$$c = v + m \qquad (16)$$

With data on the employment per sector (e_i) and the direct employment creation of the project under consideration (e_{dir}) it is now also possible to calculate the total employment created by the project. Therefore, it is again necessary first to normalise the employment figures:

$$\forall_i : \quad e_{nr,i} = \frac{e_i}{x_i} \qquad (17)$$

after which the total employment creation can be calculated in a similar way as in Equation 15:

$$e = e_{dir} + \Delta e_{ind} = e_{dir} + E_{nr}\,\Delta X \qquad (18)$$

Employment per sector could be split into different types of employment, such as low, medium and high cost employment. In this case, each type of employment gives one input vector e_i and one resulting vector e.

Annex H Breakdown of the delivered fuel costs

Table Annex H-1. Breakdown of delivered costs for pure rapeseed oil from Belgium rapeseed (Chain 1).

	Parameters	Delivered costs (€/GJ pure plant oil)
Rapeseed production		
Pesticides[1]	300 €/ha	6.99
Fertiliser	110 €/ha	2.56
Seeds	51 €/ha	1.70
Diesel[2]	73 €/ha	1.19
Wages[3]	253 €/ha	5.90
Yield	3.483 tonne rapeseed/ha	
Straw	-29 €/tonne	-1.69
Yield	2.5 tonne straw/ha	
Rapeseed transport[4]		
Diesel	0.12 €/tonne rapeseed	0.01
Wages	3.2 €/tonne rapeseed	0.26
Conversion[5]		
Energy for drying / storage	3.93 €/tonne rapeseed oil	0.11
Energy for pressing	7.08 €/tonne rapeseed oil	0.19
Capital	135 €/tonne rapeseed oil	3.65
Yield	0.333 tonne rapeseed oil/tonne rapeseed	
Rape cake	-106 €/tonne rape cake	-5.16
Yield	0.6 tonne rape cake/tonne rapeseed	
Distribution	none	0.00
Total delivered costs		**15.70 €/GJ_{LHV}** **0.58 €/kg** **0.53 €/l**

1) In total 611 Dfl2000/ha, or about 300 €/ha (PAV 2000).

2) Direct diesel use is 102 Dfl2000/ha (PAV 2000), we assume that 25% of the contract work costs also resides in diesel (see note 3).

3) Mowing is done by a contract worker for 175 Dfl_{2000} or about 90 € /ha [PAV, 2000]. We assume this resides for 75% in wages and 25% in diesel use. Other work is done in 11.5 hour. The minimum wage including social taxes for an employee in agriculture and mixed companies in 2004 was [Campens, 2006]: 13.30 €/hour for an educated employee (18-65 years), and 11.76 €/hour for an uneducated employee (18-65 years). We apply the average of these wages. We therefore assume that the other work costs 144 €/ha. If we derive the wages are derived from the difference of other costs with the market price of 205 €/tonne (Annex C) FO, Licht 2005], the result is 276 €/ha.

4) 8 tonne over 5 km by tractor consumes 0.2 kg diesel/km which costs 1 €/l. To transport 1 tonne would therefore cost about 0.12 €. We assume that the work per tonne transported amounts about 15 minutes, or 3.2 € (12.6 €/h).

5) Energy for drying and storage is costs 1.57 €/tonne rapeseed. Energy for pressing costs 2.83 €/tonne rapeseed. Capital costs is 54.14 €/tonne rapeseed (Annex C). Yields according to Pelkmans et al. [2006].

Table Annex H-2. Breakdown of delivered costs for biodiesel from Belgium rapeseed (Chain 2a).

	Parameters	Delivered costs (€/GJ biodiesel)
Rapeseed production[1)]		
Pesticides	300 €/ha	5.77
Fertiliser	110 €/ha	2.12
Seeds	51 €/ha	0.98
Diesel	73 €/ha	1.40
Wages	253 €/ha	4.87
Yield	3.483 tonne rapeseed/ha	
Straw	-29 €/tonne	-1.40
Yield	2.5 tonne straw/ha	
Rapeseed transport[2)]		
Diesel	1.05 €/tonne rapeseed	0.07
Wages	4.2 €/tonne rapeseed	0.28
Conversion[3)]		
Energy	42.15 €/tonne biodiesel	1.18
Capital	191 €/tonne biodiesel	1.21
Methanol	26.2 €/tonne biodiesel	0.70
Yield	0.4 tonne biodiesel/tonne rapeseed	
Rape cake	-106 €/tonne rape cake	-3.91
Yield	0.55 tonne rape cake/tonne rapeseed	
Glycerine	-340 €/tonne glycerine	-0.80
Yield	0.0352tonne glycerine/tonne rapeseed	
Distribution	0.12 €/l	3.57
Total delivered costs		**16.06 €/GJ_{LHV}** **0.60 €/kg** **0.54 €/l**

1) See notes under Table Annex H 1.

2) Tractor 8 tonne 5 km consuming 0.2 kg/km, truck 28 tonne 10 and 50 km consuming 0.43 kg/km, total is 1.05 kg diesel/tonne rapeseed transported, which costs 1 €/l. The time involved is estimated to amount about 20 minutes/tonne or 4.2 €/tonne

3) Energy costs 15.68 €/tonne rapeseed (Annex I). Capital according to VUB 71.02 €/tonne rapeseed (Annex I). We assume this covers both pressing and esterification. Ecofys [2005] estimates the costs of esterification to amount 40 - 50 €/tonne biodiesel. Yields are taken from the lifecycle assessment. Methanol costs about 240 €/tonne.

4) The distribution costs are assume to amount 0.12 €/l for biodiesel [Pelkmans et al., 2006; Van den Broek et al., 2003].

.

Table Annex H-3. Breakdown of delivered costs for biodiesel from rapeseed imported from Poland (Chain 2b).

	Parameters	Delivered costs (€/GJ biodiesel)
Rapeseed import[1)]	205 €/tonne rapeseed	13.74
Rapeseed transport[2)]		
Diesel	3.02 €/tonne rapeseed	0.20
Wages	1 €/tonne rapeseed	0.07
Import	0.77 €/tonne rapeseed	0.05
Conversion[3)]		
Energy	44.16 €/tonne biodiesel	1.18
Capital	200 €/tonne biodiesel	5.36
Methanol	26.2 €/tonne biodiesel	0.70
Yield	0.4 tonne biodiesel/tonne rapeseed	
Rape cake	-106 €/tonne rape cake	-3.91
Yield	0.55 tonne rape cake/tonne rapeseed	
Glycerine	-340 €/tonne glycerine	-0.80
Yield	0.0352tonne glycerine/tonne rapeseed	
Distribution[3)]	0.12 €/l	3.57
Total delivered costs		**20.17 €/GJ_{LHV}** **0.75 €/kg** **0.68 €/l**

1) Annex C; FO Licht, 2005].
2) Ship 70,000 tonne 1800 km consuming 60 kg/km, this corresponds to 1.5 €/tonne rapeseed transported, half of the diesel consumption is assumed to be allocated to import. Barge 1000 tonne 150 km.
3) See notes under Table Annex H 2.

Table Annex H-4. Breakdown of delivered costs for biodiesel from rapeseed oil imported from Canada (Chain 2c).

	Parameters	Delivered costs (€/GJ biodiesel)
Rapeseed oil import[1)]		
Direct costs	539 €/tonne rapeseed oil	15.52
Import tax	17.2 €/tonne rapeseed oil	0.49
Rapeseed oil transport[2)]		
Diesel	5.08 €/tonne rapeseed oil	0.14
Wages	1 €/tonne rapeseed oil	0.03
Import	2.83 €/tonne rapeseed oil	0.08
Conversion[3)]		
Energy	27.45 €/tonne biodiesel	0.74
Capital	74.76 €/tonne biodiesel	2.00
Methanol	26.2 €/tonne biodiesel	0.70
Yield	0.95 tonne biodiesel/tonne rapeseed oil	
Glycerine	-340 €/tonne glycerine	-0.91
Yield	0.095tonne glycerine/tonne rapeseed oil	
Distribution[4)]	0.12 €/l	3.57
Total delivered costs		**22.05 €/GJ_{LHV}** **0.82 €/kg** **0.74 €/l**

1) Rapeseed oil on the world market costs about 550 €/tonne [Ecofys, 2005], 539 €/tonne on average over 2005 [FO Licht, 2005]. Import tax is 3.2%.
2) Ship 70,000 tonne 6600 km consuming 60 kg/diesel/km, this corresponds to 5.66 €/tonne rapeseed oil transported. Half of this is assumed to be import. Barge 1000 tonne 150 km consumes 15 kg/km. We assume that about 5 minutes/tonne rapeseed is involved in the barge, or 1 €/tonne, and that the wages involved in international transport are negligible (on a per tonne basis).
3) Yields are 0.95 kg biodiesel/kg refined oil and 0.095 kg glycerine/kg refined oil.
4) See notes under Table Annex H 2.

Table Annex H-5. Breakdown of delivered costs for biodiesel from Belgium waste vegetable oil (Chain 2d).

	Parameters	Delivered costs (€/GJ biodiesel)
Waste vegetable oil[1)]	40 €/tonne	1.13
Waste vegetable oil transport[2)]		
Diesel	1.54 €/tonne oil	0.04
Wages	1.05 €/tonne oil	0.03
Refining[3)]		
Capital	70 €/tonne	1.98
Electricity	70 €/tonne	1.98
Wages	70 €/tonne	1.98
Conversion[4)]		
Energy	27.45 €/tonne biodiesel	0.74
Capital	74.76 €/tonne biodiesel	2.00
Methanol	26.2 €/tonne biodiesel	0.70
Yield	0.95 tonne biodiesel/tonne rapeseed oil	
Glycerine	-550 €/tonne glycerine	-1.47
Yield	0.095tonne glycerine/tonne rapeseed oil	
Distribution[4)]	0.12 €/l	3.57
Total delivered costs		**12.67 €/GJ_{LHV}** **0.47 €/kg** **0.43 €/l**

1) VUB assumes that waste vegetable oil market price costs 250 €/tonne (Annex C), this equals about the price for collected and refined waste vegetable oil. At the collection points we assume that the price is rather some 40 €/tonne (coming from negative values in the previous years).

2) Truck 28 tonne 100 km consuming 0.43 kg diesel/km, or 1.54 kg diesel/tonne oil transported. The time involved is estimated to amount about 5 minutes/tonne.

3) Refining of waste vegetable oil up to quality suitable for esterification costs about 250 - 40 €/tonne (see note 1), part of this is in wages, part in energy use, part in capital. Due to lacking knowledge on the details we assume each contributes a third.

4) See notes under Table Annex H 2.

Table Annex H-6. Breakdown of delivered costs for bioethanol, half from Belgium wheat and half from imported Polish wheat (Chain 3a).

	Parameters		Delivered costs (€/GJ bioethanol)
Wheat[1]			
Pesticides	280 €/ha	50% contribution	1.71
Fertiliser	125 €/ha		0.76
Diesel	76 €/ha		0.46
Seeds	175 €/ha		1.07
Wages	362 €/ha		2.21
Yield	8.4 tonne/ha		
Straw	-29 €/ha		-0.78
Yield	4.4 tonne/ha		
Import	95 €/tonne	50% contribution	4.86
Wheat feedstock transport[2]			
Diesel	1.68 €/tonne wheat		0.17
Wages	2.63 €/tonne wheat		0.27
Import	0.95 €/tonne wheat		0.10
Conversion[3]			
Energy	297 €/tonne		11.25
Capital	100 €/tonne bioethanol		3.79
Yield	0.37 tonne ethanol/tonne wheat		
Animal feed	-114 €/tonne		-5.03
Yield	0.431 tonne animal feed/tonne wheat		
Distribution[4]	0.125 €/l		5.99
Total delivered costs			**26.82 €/GJ_{LHV}** **0.71 €/kg** **0.56 €/l**

1) Pesticides cost in total 551 Dfl $_{2000}$/ha, or about 280 €/ha [PAV, 2000: winter wheat in south west of Netherlands). The direct application of diesel are 97 Dfl_{2000}/ha, we assume that 25% of the contract work costs also resides in diesel. Yields are the same as assumed for the Lifecycle assessment. For the present study we have assumed that the Belgium wheat price is about 106 €/tonne. The difference between mentioned costs and the price is assumed to be wage for the farmer. Polish wheat (before transport) costs 95 €/tonne.

2) Half of the wheat is transported by tractor 8 tonne 5 km, truck 28 tonne 10 km, Barge 1000 tonne 80 km, which requires 1.47 kg diesel/tonne and involves about 15 minutes work/tonne (estimate). The other half is transported by a ocean ship 70 ktonne 1800 km and barge 1000 tonne 150 km, which requires 3.79 kg diesel/tonne, half of which is allocated to diesel and half to import. The work involved amounts about 10 minutes/tonne (international transport negligible, see Table Annex H 2, note 4).

3) Energy costs 84.55 €/tonne wheat, Capital 28.59 €/tonne wheat (Annex I). Yields are 360 l or 285 kg ethanol/tonne fresh grains and 431 kg animal feed/tonne fresh grains (lifecycle assessment of this project).

4) Delivery of ethanol costs 0.125 €/l, this includes the normal distribution costs of gasoline, the extra costs due to extra fuel logistic services, and adaptation of the gasoline to meet vapour pressure specifications [Pelkmans et al., 2006; Van den Broek et al., 2003].

Table Annex H-7. Breakdown of delivered costs for bioethanol from Belgium sugar beet (Chain 3b).

	Parameters	Delivered costs (€/GJ bioethanol)
Sugar beet[1)]		
Pesticides	130 €/ha	1.21
Fertiliser	170 €/ha	1.58
Diesel	157 €/ha	1.46
Seeds	249 €/ha	2.31
Wages	2531 €/ha	23.52
Yield	59.6 tonne/ha	
Sugar beet feedstock transport[2)]		
Diesel	0.77 €/tonne sugar beet	0.43
Wages	0.45 €/tonne sugar beet	0.25
Conversion[3)]		
Energy	76.4 €/tonne ethanol	2.89
Capital	87.1 €/tonne ethanol	3.30
Yield	0.0684 tonne ethanol/tonne sugar beet	
Pulp (for animal feed)	-5.16 €/tonne pulp	-4.46
Yield	1.56 tonne pulp/tonne sugar beet	
Distribution[4)]	0.125 €/l	5.99
Total delivered costs		**38.47 €/GJ_{LHV}** **1.02 €/kg** **0.80 €/l**

1) Pesticides total 276 Dfl_{2000}/ha, fertiliser 339 Dfl_{2000}/ha, direct diesel use 101 Dfl_{2000}/ha, contract work (851 Dfl_{2000}/ha) is assumed to consist of 75% wages and 25% energy, further work required is 19.6 h/ha. [PAV, 2000: south west of the Netherlands). The market price of A and B sugar beets is 54 €/tonne beet containing at least 16% sugar. This is not the beet expected to be used for ethanol production, but we assume that the farmer will require a similar price. The wages are both for the farmer and the contract workers.

2) Truck 28 tonne 50 km requires 0.77 kg diesel/tonne sugar beet transported, work is estimated to amount 0.45 €/tonne.

3) Energy costs 5.23 €/tonne sugar beet, Capital 5.96 €/tonne sugar beet (Annex I). Yields and co-product price are taken from the lifecycle assessment of this project.

4) See notes under Table Annex H 6.

Table Annex H-8. Breakdown of delivered costs for bioethanol imported from Brazil (Chain 3c).

	Parameters	Delivered costs (€/GJ bioethanol)
Sugar cane[1)]		
Import	372 €/tonne bioethanol	14.09
Import tax	10.2 €/100 litres	4.88
Ethanol international transport[2)]		
Diesel	2.91 €/tonne bioethanol	0.11
Import	2.91 €/tonne bioethanol	0.11
Distribution[3)]	0.125 €/l	5.99
Total delivered costs		**25.18 €/GJ_{LHV}** **0.66 €/kg** **0.53 €/l**

1) Anhydrous ethanol in Brazil ex-distillery costed about 295 €/m^3 in 2005 [FO Licht, 2005].

2) Ocean freight 100 ktonne 9700 km consuming 60 kg/km, half of which is allocated to diesel from Belgium, half to diesel bought elsewhere. Wages are negligible.

3) See notes under Table Annex H 6.

Table Annex H-9. Breakdown of delivered costs for bioethanol from Belgium wood (Chain 3d).

	Parameters	Delivered costs (€/GJ bioethanol)
Wood[1)]		
Pesticides	15 €/ha	0.25
Fertiliser	117 €/ha	1.94
Diesel	190 €/ha	3.16
Other	21.8 €/tonne dry wood	3.62
Yield	10 tonne dry wood/ha	
Wood feedstock transport[2)]		
Diesel	0.77 €/tonne dry wood	0.13
Wages	0.45 €/tonne dry wood	0.07
Conversion[3)]		
Capital	248 €/tonne bioethanol	-3.18
Energy	-84 €/tonne bioethanol	9.39
Operating and maintenance	115.5 €/tonne bioethanol	4.38
Yield	0.228 tonne bioethanol/tonne dry wood	
Distribution[4)]	0.125 €/l	5.99
Total delivered costs		**25.75 €/GJ_{LHV}** **0.68 €/kg** **0.54 €/l**

1) Pesticides amount about 0.75 kg glyphosate (see lifecycle assessment) costing about 16.45 Dfl_{2000}/kg42% [PAV, 2000], this results in a higher cost than assumed by VUB elsewhere in this study (1.38 €/ha), but the VUB number only applies to the energy contained in the pesticide. Fertiliser use is 108 kg K_2O, 60 kg P_2O_5 and 75 kg N (same as in lifecycle assessment) which costs about 234 Dfl_{2000}/ha [PAV, 2000]. The direct diesel use is 190 kg diesel/ha (see lifecycle assessment). The amount of work is unknown, but in any case much smaller than in the production of agricultural feed crops. Total must amount at least some 3 €/GJ, or 54 €/tonne wood (international market price), this is achieved by introducing the item "other" which represents other costs made in the agricultural sector.

2) See notes under Table Annex H 5.

3) Net energy produced is 2.678 MWh_e/tonne bioethanol (costing 0.086 €/kWh_e). Capital costs are 78.72 €/tonne dry wood, or 281.1 €/tonne bioethanol. Hamelinck [2005] estimates the investments to amount 291 M€ for a 400 MWHHV biomass input factory. This correlates to about 40 M€ capital costs per year for a 72 tonne dry wood/hr installation. In other words, the contribution of capital costs is rather 69 €/tonne wood, or 248 €/tonne bioethanol. On the short term, the conversion efficiency from wood to ethanol is 34.9% (HHV), or 0.228 tonne bioethanol/tonne wood. 4.1% power is co-produced, or 222 kWhe/tonne wood, or 84 €/tonne bioethanol. Annual operating and maintenance is 6.4% of the investments, or 32.3 €/tonne wood, or 115.5 €/tonne bioethanol

4) See notes under Table Annex H 6.

Table Annex H-10. Breakdown of delivered costs for bioethanol from Canadian wood (Chain 3e).

	Parameters	Delivered costs (€/GJ bioethanol)
Wood[1)]		
Import	54 €/tonne dry wood	8.97
Wood feedstock transport[2)]		
Diesel	4.33 €/tonne dry wood	0.72
Wages	1.05 €/tonne dry wood	0.17
Import	2.83 €/tonne dry wood	0.47
Conversion[3)]		
Capital	248 €/tonne bioethanol	-3.18
Energy	-84 €/tonne bioethanol	9.39
Operating and maintenance	115.5 €/tonne bioethanol	4.38
Yield	0.228 tonne bioethanol/tonne dry wood	
Distribution[4)]	0.125 €/l	5.99
Total delivered costs		**26.91 €/GJ$_{LHV}$** **0.71 €/kg** **0.56 €/l**

1) Wood imported from the world costs about 3 €/GJ [Hamelinck, 2005].
2) Ship 70 ktonne 6600 km consuming 60 kg diesel/km, half allocated to import, half to Belgium diesel. Barge 1000 tonne 100 km consuming 15 kg diesel/km. Estimated time (for barge) involved is 5 minutes/tonne.
3) See notes under Table Annex H 9.
4) See notes under Table Annex H 6.

Table Annex H-11. Breakdown of delivered costs for FT diesel from Belgium wood (Chain 4a).

	Parameters	Delivered costs (€/GJ bioethanol)
Wood[1)]		
Pesticides	15 €/ha	0.17
Fertiliser	117 €/ha	1.36
Diesel	190 €/ha	2.21
Other	21.8 €/tonne dry wood	2.54
Yield	10 tonne dry wood/ha	
Wood feedstock transport[2)]		
Diesel	0.77 €/tonne dry wood	0.09
Wages	0.45 €/tonne dry wood	0.05
Conversion[3)]		
Energy	-433 €/tonne FT diesel	-10.09
Capital	509 €/tonne FT diesel	11.86
Yield	0.20 tonne FT diesel/tonne dry wood	
Distribution[4)]	0.11 €/l	3.33
Total delivered costs		**11.54 €/GJ$_{LHV}$** **0.49 €/kg** **0.38 €/l**

1) Pesticides amount about 0.75 kg glyphosate (see lifecycle assessment) costing about 16.45 Dfl$_{2000}$/kg42% [PAV, 2000], this results in a higher cost than assumed by VUB elsewhere in this study (1.38 €/ha), but the VUB number only applies to the energy contained in the pesticide. Fertiliser use is 108 kg K_2O, 60 kg P_2O_5 and 75 kg N (same as in lifecycle assessment) which costs about 234 Dfl$_{2000}$/ha [PAV, 2000]. The direct diesel use is 190 kg diesel/ha (see lifecycle assessment). The amount of work is unknown, but in any case much smaller than in the production of agricultural feed crops. Total must amount at least some 3 €/GJ, or 54 €/tonne wood (international market price), this is achieved by introducing the item "other".
2) See notes under Table Annex H 5.
3) Net energy produced is 5.046 MWh$_e$/tonne biodiesel (costing 0.086 €/kWh$_e$). Capital costs are 71.20 €/tonne dry wood, or 509 €/tonne biodiesel.
4) Distribution of FT diesel is estimated to costs as much as the distribution of regular diesel, 0.11 €/l.

Table Annex H-12. Breakdown of delivered costs for BTL from Canadian wood (Chain 4b).

	Parameters	Delivered costs (€/GJ BTL)
Wood[1)]		
Import	54 €/tonne dry wood	8.99
Wood feedstock transport[2)]		
Diesel	4.33 €/tonne dry wood	0.72
Wages	1.05 €/tonne dry wood	0.17
Import	2.83 €/tonne dry wood	0.47
Conversion[3)]		
Energy	-433 €/tonne biodiesel	-10.09
Capital	509 €/tonne biodiesel	11.86
Yield	0.20 tonne biodiesel/tonne dry wood	
Distribution[3)]	0.11 €/l	3.33
Total delivered costs		**12.27 €/GJ_{LHV}** **0.53 €/kg** **0.41 €/l**

1) Wood imported from the world costs about 3 €/GJ [Hamelinck, 2005].

2) Ship 70 ktonne 6600 km consuming 60 kg diesel/km, half allocated to import, half to Belgium diesel. Barge 1000 tonne 100 km consuming 15 kg diesel/km. Estimated time (for barge) involved is 5 minutes/tonne.

3) See notes under Table Annex H 11.