EXECUTIVE SUMMARY

ABSTRACT

The overall objective of the work was to analyze and compare the most promising possibilities of using the limited biomass resources in Belgium. The amounts of domestic available biomass are first reported in terms of available agricultural, forest areas and waste streams. The different potential uses of the available resources (land in particular) are next compared in terms of overall energy efficiency, surface requirements, greenhouse balances and to some extent complete Life Cycle Analysis (LCA). A new method called System Perturbation Analysis (SPA) has been developed by the VUB to assess the impact of the different biomass uses within a given system which in this case is Belgium. The different possible uses of wood are finally compared for both transport, heat and power applications.

IS THERE ENOUGH BIOMASS AVAILABLE ?

Finding the amount of biomass resources 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.

According to the literature, following definitions of (biomass) potential can be given :

- The theoretical potential is defined as the total annual production of all resources given no limits. It represents the total quantity of biomass resources in a region and can be considered as the upper bound of available 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).

Part of this potential is expected to come from arable and forest land resources, which in Belgium roughly amount to some 1400 kha arable and 700 kha forest areas. Forest area is found mainly in the Walloon region. Arable land is more equally distributed but is still more important in the Walloon region. According to the study, the surface requirements to replace a limited part of some 400 PJ liquid fossil fuels used yearly in Belgium can be sketched in Table 1. The surface requirements for the different biofuels (mainly ethanol and biodiesel) are found to range between 10 and 40 kha per replaced PJ liquid fuel. From Table 1 it appears that 5 to 10% of the arable land is needed for every 1% replacement at tank level (for 400 PJ). It must also be stressed that replacing 1 GJ of fossil fuel at the car level does not mean saving 1 GJ fossil fuel globally, as will be discussed below.

Table 2 summarises the estimations of 'acceptable' surface allocations for the major crops. Short Rotation Forestry will need more time to penetrate the market because of major barriers such as high long term risk (20 years engagement), lack of experience, huge juridical uncertainty and incomes which are not attractive for the farmers. From Tables 1 and 2 it appears that other resources than arable land must be used to achieve reasonable replacement percentages. Surface requirements can however reduce as yields are continuously improved by application of biotechnology and a doubling of yields is considered as feasible on the medium to long term. Development of Short Rotation Forestry and wood from forest residues increase the potential significantly, but use of wood for liquid fuels is in competition with other uses such as power, heat, construction material and even biomaterials such as bio-plastics.

Table 3 gives a summary of the overall potentials found within the Libiofuels project for the production of raw energy from biomass. These numbers are too low to cover all the goals set for biomass use in both the transport, heat and/or power production. Increased import from Europe and beyond is therefore highly probable.

The picture for the EU as a whole shows a better balance between available biomass and targets, which means that Europe as a whole may be less dependant upon imports. More details about the EU and world biomass availability can be found in the Libiofuels report.

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

Table 1: Overall requirements for liquid biofuels for transport when using agricultural surface only, percentages of the available arable land assuming 400 PJ/year liquid fuel demand.

year	Rapeseed	Winter wheat	Sugar beet	Short rotation forest	Total
2010	0.5%	2.1%	1.1%	-	2.7%
2015	1.1%	4.8%	2.6%	0.01%	8.5%

Table 2: Estimation of acceptable arable land allocation for energy crops, percentages of the available arable land.

PJ/year	2005	2010	2015
Technical biomass potential	36	39	58
Socially acceptable biomass potential	11	21	43
Achievable biomass potential	2.7	8.6	32

Table 3: Technical, socially acceptable and achievable gross biomass energy potentials in Belgium according to the Libiofuels project.

SELECTED BIOMASS USAGES

Figure 1 summarizes most of the possible routes to replace fossil fuels by biofuels in both automotive and heat & power applications, with the exclusion of hydrogen production for fuel cells and some other more exotic potential applications. So far, the analysis has been made only for the routes which are considered as relevant on the short to medium term (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, namely biodiesel from wood through Fisher-Tropsch synthesis and ethanol from wood through hydrolysis. In the framework of the Libiofuels project, it was decided not to further study biogas, hydrogen and dimethylester (DME). Both hydrogen and DME will most likely not be available before 2040. Biogas is suspected to be of little importance for automotive applications in Belgium, but it seems to be an interesting option for treatment of by-products from the other routes. It is finally to be observed that liquid fuels obtained from biomass can be (and effectively are) used in heat and power applications.

Bioethanol is a fermentation ethyl alcohol which can be further transformed into ETBE (Ethyl-Tri-Butyl Ether) by adding fossil isobutylene. Ethanol can replace a limited amount of gasoline whereas ETBE can fully replace the fossil methanol based MTBE which is used as an octane enhancer. If ethanol is used pure or in high concentrations it may damage engine parts made of certain plastics, elastomers and metals like steel, aluminum and magnesium. Fermentation, distillation and drying processes for ethanol production are energy intensive and reduce the efficiency of the conversion process, unless e.g. straw from the wheat can be used for heat supply. Production of ethanol from wheat and sugar beet produce considerable amounts of protein rich residues for use as animal feed. About half of the energy leaving the process in contained in this animal feed which must be taken into account in any energy balance exercise.

Pure plant oil or PPO is easy to produce but some engine modifications are needed when blending diesel with more than 50% PPO. Biodiesel has properties much closer to the conventional diesel, although it is still advised to blend no more than 30% biodiesel into diesel because of its corrosiveness. The process of making biodiesel from vegetable oils is called trans-esterification, which is a well-known process and largely applied. If produced from rapeseed, the biodiesel is called RME (Rapeseed Methyl Ester), if produced from used vegetable oil it is called FAME (Fatty Acid Methyl Ester). The process consumes methanol and produces glycerin as a residue, which finds its way in the market as a high value product (cosmetics, paints, food industry, pharmaceuticals, etc..).

Biodiesel can also be produced from wood through prior gasification, gas cleaning and Fischer-Tropsch synthesis. This process is still to be demonstrated for biomass application, where the most critical and uncertain steps are the integration of biomass gasification and the cleaning of the synthetic gas. The resulting biodiesel can easily be mixed with fossil diesel, applied in current diesel engines and in the existing diesel distribution network without any specific adaptations. However, additives may be necessary to meet all the diesel standards.

Wood can finally be used for heat and/or power production through direct combustion in selected cases which are co-combustion in steam plants (e.g. Ruien Electrabel plant), full combustion in steam plants (e.g. Les Awires), pure heat production in small to medium size boilers (e.g. Vyncke boilers) and finally small scale combined heat and power through Organic Rankine Cycle (ORC) which is the sole commercially available and viable alternative for external combustion in the small scale (e.g. Turboden, Italy). Gasification in a fixed bed gasifier combined with internal combustion engines is considered as the sole available and viable alternative for internal combustion of biomass (e.g. Xylowatt, Belgium).

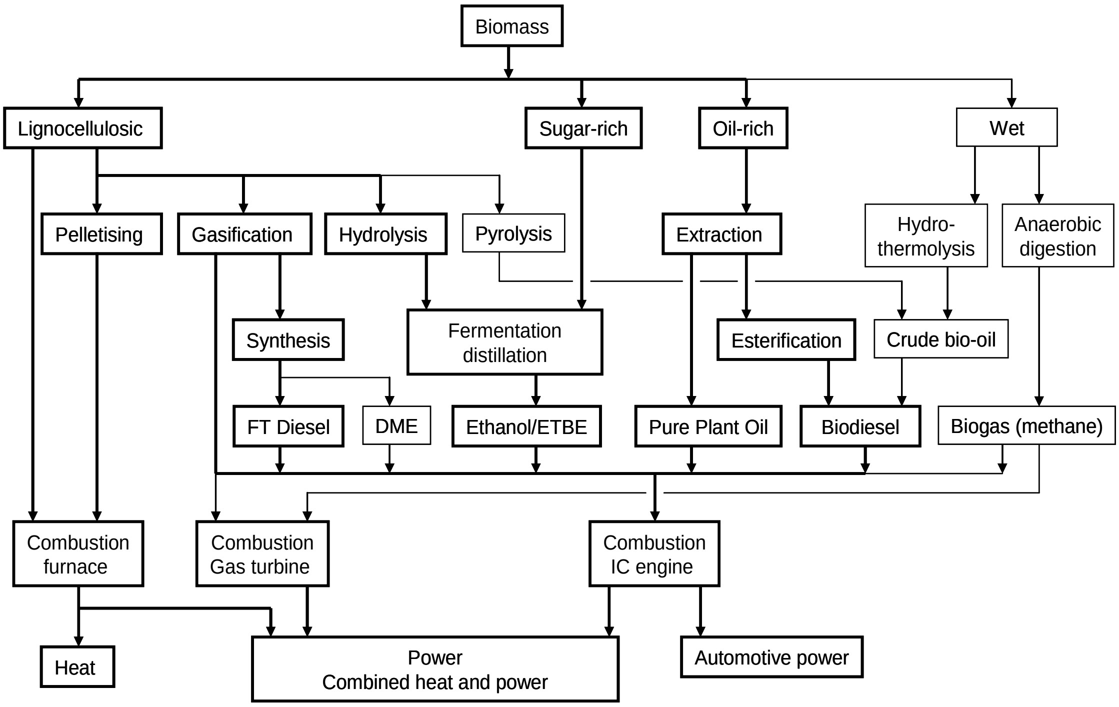

Fig 1 : Main routes for use of biomass for transport, heat and/or power production. Fat lines are considered in the Libiofuels project.

GREENHOUSE BALANCES AND LIFE CYCLE ANALYSIS

Utilities are consumed and pollutants are emitted throughout the lifecycle of any fuel used for energy. Life cycle analysis aims at calculating these consumptions and emissions in the different parts of the lifecycle, which are feedstock production, transport of the raw material and products, conversion of the feedstock into a transportation fuel, and use of the fuel in cars. Libiofuels mainly reports on the greenhouse gas emissions and net energy savings, but in three cases (wheat and sugar beet for ethanol, rapeseed for biodiesel) other impacts are analysed such as acidification, eutrophication, toxication, ozone layer depletion and photochemical smog. Details of methodology and data available in the Libiofuels report.

Results for the greenhouse gas balances are shown in Figures 2 and 3. All analysed cases lead to a net reduction of greenhouse gas emissions. For rapeseed oil and rapeseed biodiesel (1 and 2a-c), the reduction is about 40 %, the majority of the greenhouse gas emissions is in agriculture, more specific in N2O from the production and application of fertiliser. No CO2 is allocated to used vegetable oil (2d) because the feedstock is considered a waste product. The bioethanol chains show varied results. Bioethanol from wheat (chain 3a) yields a limited CO2 reduction owing to the energy intensive production and conversion processes (if fed by fossil fuel). Ethanol from sugar beet and from sugar cane profit from higher yields per hectare and (relatively) lower fertiliser input. According to this analysis, the best greenhouse gas emission reduction in the ethanol cases should be realised with the use of ethanol from woody biomass.

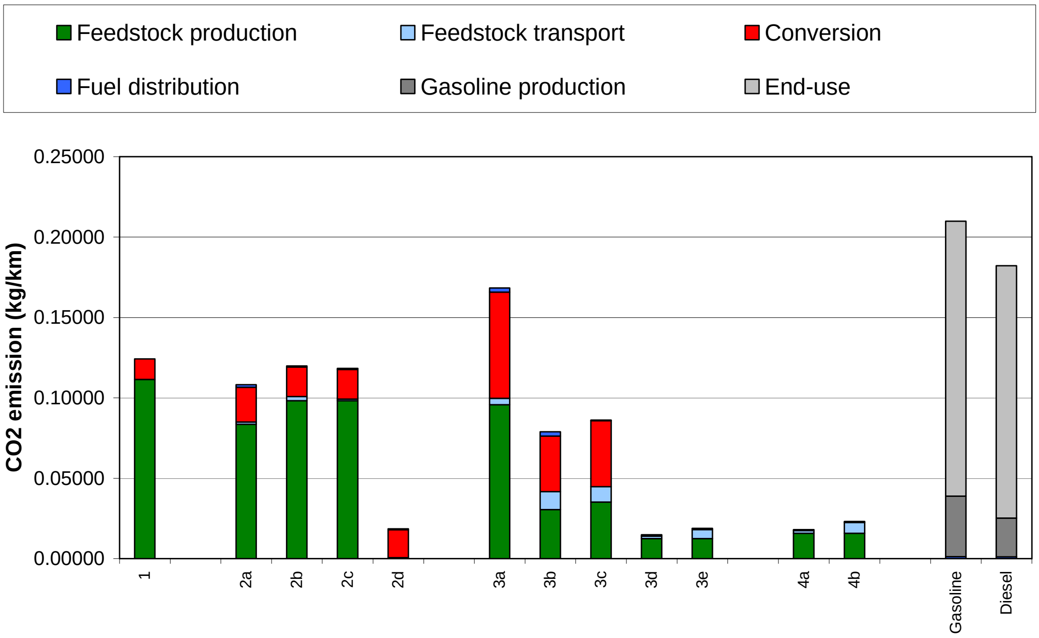

Fig 2 : CO2 emission from the different biofuel routes, compared with fossil diesel and fossil gasoline. 1: PPO, 2: Biodiesel from rapeseed (a: local rapeseed, b: imported rapeseed, c: imported oil, d: used vegetable oil), 3: Ethanol (a: local/imported wheat, b: sugar beet, c: imported ethanol, d: local SRF, d: imported wood), 4=FT diesel (a: local SRF, b: imported wood).

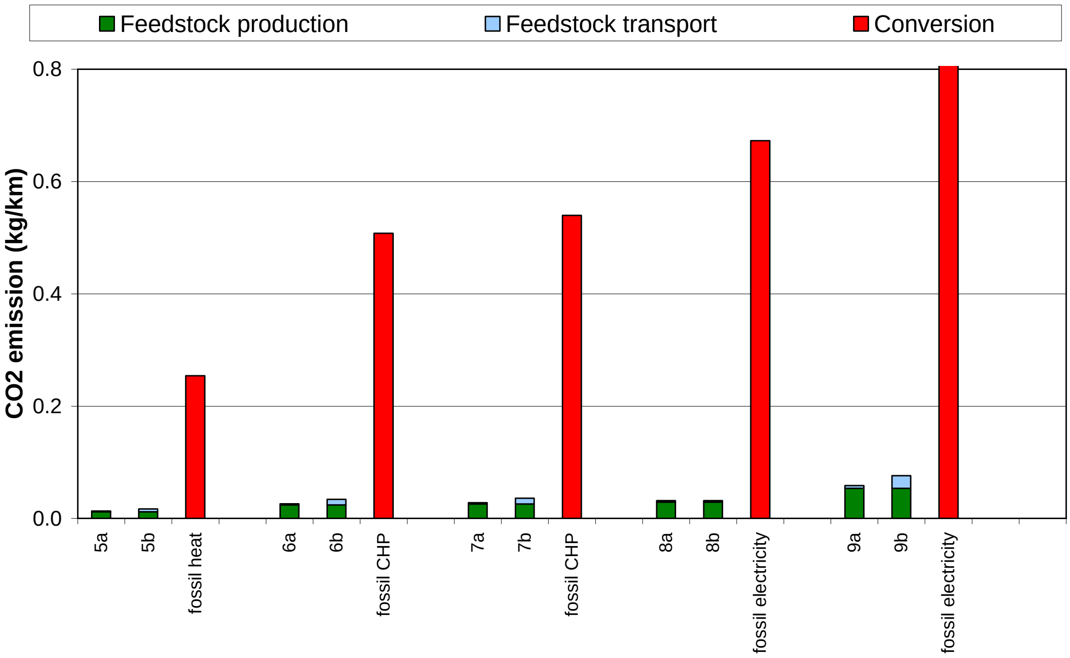

Fig 3 : CO2 emission from the different biofuel routes, compared with fossil heat and power. 5: heat boiler, 6: ORC, 7: gasifier/IC engine, 8: co-combustion, 9: medium scale steam plant, a: local SRF, b: imported wood.

Finally, Fischer-Tropsch diesel (4) shows a reduction of about 90 % over the use of fossil diesel. The conversion from wood to diesel is almost energy neutral, because of the co-production of heat and electricity within the process and provided all the heat can be valorised. The heat and CHP cases (Figure 3, cases 5 to 7) are compared to systems on natural gas as reference. The power cases (8 and 9) are compared to a mix of coal (30 %) and natural gas (70 %). All the heat and/or power cases yield very high CO2 reductions.

Figure 4 illustrates one of the LCA results. For all 14 criteria a relative comparison is made between the rapeseed case (leftmost columns) with the reference fossil diesel case (rightmost columns). The results within each impact are normalised to 100 % for the chain with the strongest impact. The two leftmost groups are already discussed above and have a high decision impact. From the other categories the human toxicity is the most important, and both options are comparable. The biodiesel has bad scores for most of the other criteria but globally speaking the balance is well in favour of the biodiesel. The LCA for ethanol show results in the same line as the biodiesel case.

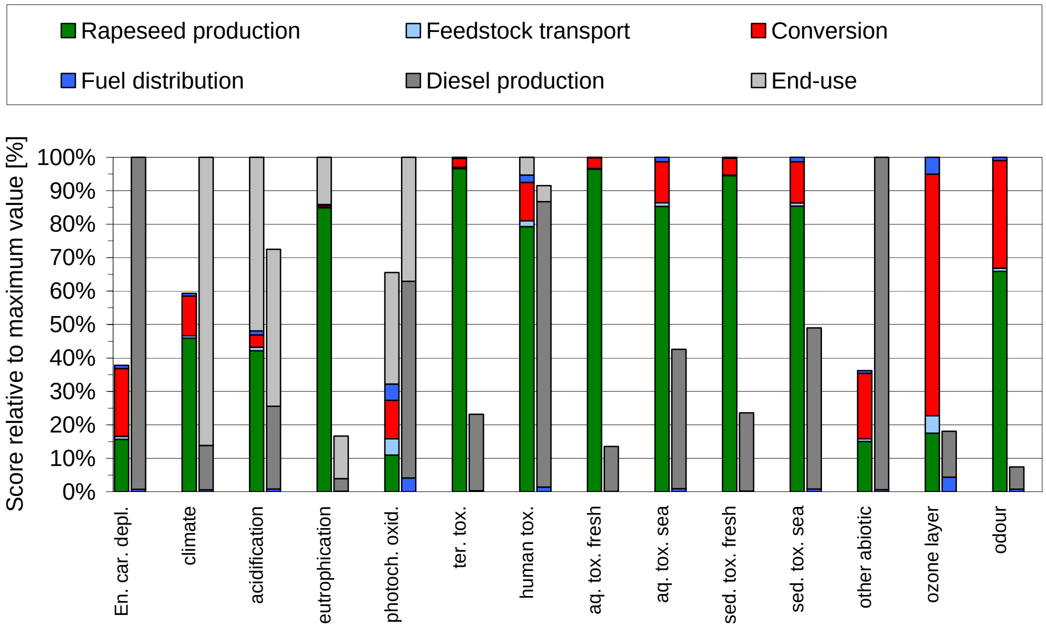

Fig 4 : LCA results for the local rapeseed to biodiesel case. Left columns represent the biodiesel values, the right columns are the reference fossil diesel case.

ENERGY AND CO2 BALANCES FOR A GIVEN SYSTEM

LCA considers a chain in its totality and focuses on one single main product (biofuel in this case). Other secondary products are taken into account through allocation of 'credits' for energy and CO2eq. Such allocation is always to some extent arbitrary : it can be allocation by mass, by energy, by economic value or even other.. This allocation is therefore a disadvantage in LCA and the interpretation of results can be difficult. Accordingly a new type of analysis has been developed called System Perturbation Analysis or SPA. SPA considers a given 'system' (in casu Belgium, see Figure 5) where resources are transformed into products through the given conversion routes.

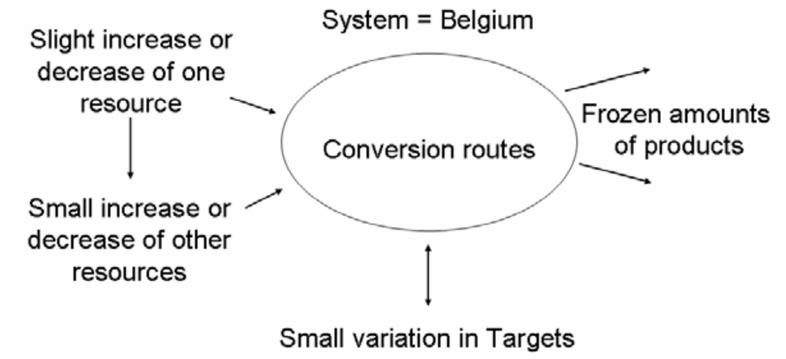

Fig 5 : System Perturbation Analysis.

The conversions lead to impacts such as CO2 emissions, costs, employment a.o., which are called 'targets'. In SPA, a single resource chosen by the user is disturbed with a specified amount. This leads automatically to a perturbation of at least one main product and maybe of several by-products. The product usage is however considered as constant and the perturbations must therefore be compensated by perturbations on at least one other resource, which on his turn may induce other perturbations in the products, etc. As an example, one 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 for animal feeding, which on their turn will affect the production or import of straw and animal feed, etc… When all perturbations are compensated, global perturbations on global energy usage and greenhouse gas emissions (and later on employment, costs a.o.) can easily be calculated. Each set of perturbations is called a 'scenario'.

SPA differs from LCA mainly because it looks to the system balances of resources and resulting targets, rather than comparing two full well-to-wheel trajectories. The problem of allocation can be avoided to a large extent and the impact of measures for biofuel enhancement and their local Kyoto impact can be quantified. Conclusions may differ mainly because of local conditions and because no allocation models must be used as in LCA.

RESULTS AND DISCUSSION

Results are shown in Figures 6 to 11. Out of 58 scenarios, the following most relevant cases are reported :

Sugar rich biomass cases :

- Wheat for ethanol, straw for bedding : wheat is produced in Belgium on set aside land, the straw is used for bedding and reduces straw import, the wheat is converted to ethanol for replacement of gasoline in cars, the residues are used as animal feed reducing its import.
- Wheat for ethanol, straw is burned : same as previous but the straw is collected and burnt for heat production (distillation) replacing natural gas
- Wheat for ethanol - imported : same as previous but the wheat is imported from neighbouring countries (allocation required)
- Sugar beat for ethanol : sugar beat is produced in Belgium on set aside land and converted to ethanol for replacement of gasoline in cars.

- Ethanol for gasoline - imported : ethanol is imported from Brazil for replacement of gasoline in cars (allocation required).

Oil-rich cases :

- Rapeseed for PPO - local : rapeseed is produced in Belgium on set aside land and pressed to PPO for replacement of diesel in cars, the residues are used for animal feed reducing its import.
- Rapeseed for RME - local : rapeseed is produced in Belgium on set aside land and converted to biodiesel (RME) for replacement of diesel in cars, the rapemeal is used for animal feed reducing its import, the glycerine is sold on the market reducing its import.
- Rapeseed for RME - imported : same as previous but the rapeseed is imported from France
- Used vegetable oil for FAME : used vegetable oil converted to biodiesel (FAME) for replacement of diesel in cars, the glycerine is sold on the market reducing its import.

Lignocellulosic cases :

- Wood for co-combustion - SRF : short rotation wood (SRF) is produced in Belgium on set aside land and used for co-combustion in a coal steam plant for replacement of coal
- Wood for CHP (FBG with PE) - SRF : same resource but the wood is used for combined heat and power production through fixed bed gasification (FBG) and piston engine (PE) for replacement of natural gas and electricity imports.
- Wood for heat - SRF : same resource but the wood is simply burned for heating purposes in an advanced wood combustion heater for replacement of fueloil.
- Wood for FT biodiesel - SRF : same resource but the wood is used in a Fisher-Tropsch biodiesel production plant for replacement of diesel in cars
- Wood for ethanol - SRF : same resource but the wood is used in a hydrolysis plant to produce ethanol for replacement of gasoline in cars.

Figures 6 and 7 first show results obtained when expanding the considered system to the 'world'. These results are almost equivalent to full LCA results and could therefore be used for validation purposes.

Figure 6 shows the global energetic efficiency of the selected cases. This efficiency is defined as the ratio of the saved fossil energy worldwide to the produced renewable energy on the field, when taking all side effects into account (including the energy in the by-products). The figure tells us to what extent fossil energy is really replaced by renewable energy : this efficiency should at least be positive and preferably close to 100% or even beyond. According to the analysis all these efficiencies are quite positive and range from 45 up to 120%. Efficiency higher than 100% is possible in the wood CHP case because SRF consumes only little amounts of energy in combination with the positive effect of CHP versus separate production in the reference case. Rapeseed, wheat and sugar beat need more energy in the production processes, and conversion consume energy, particularly in the ethanol distillation process, leading to lower overall efficiencies which are in the range of 40 to 60%. In case residues are used as fuel for energy production these efficiencies improve significantly.

Figure 7 shows the corresponding global CO2 savings, expressed in kg CO2 saved per saved GJp of primary fossil energy. For reference : direct fossil fuel emissions range between 56 kg/GJ for natural gas to 96 for coal, whereas the selected cases show savings from 42 kg/GJ to 102 kg/CO2. The CO2 balances therefore appear to be quite positive in all selected cases. Wood for co-combustion shows the highest score because the wood replaces coal which is a high CO2 emitter, in combination with a high efficiency.

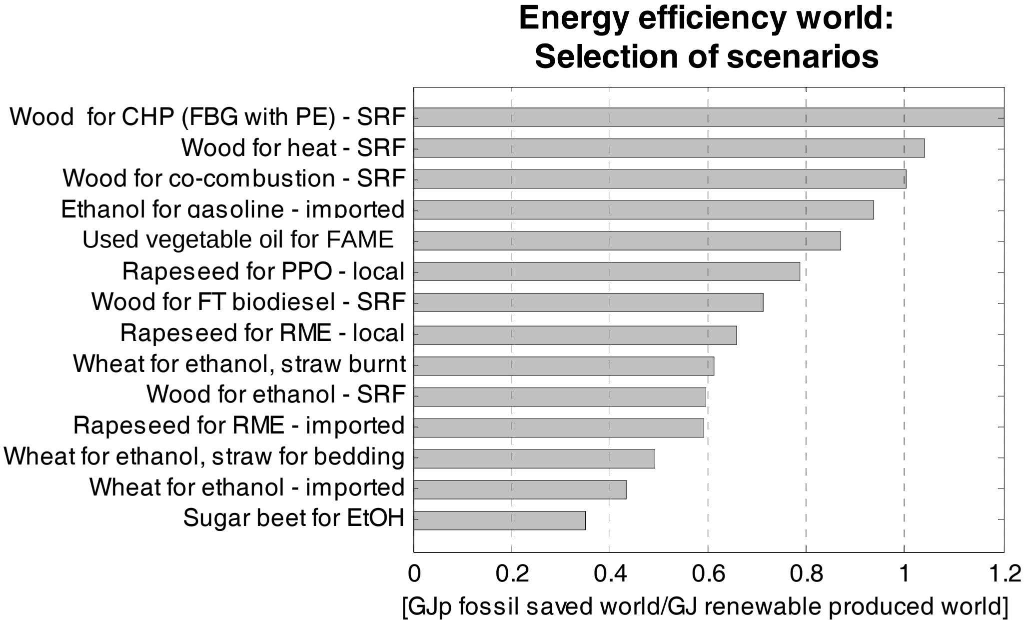

Fig 6 : SPA results for global energy efficiency.

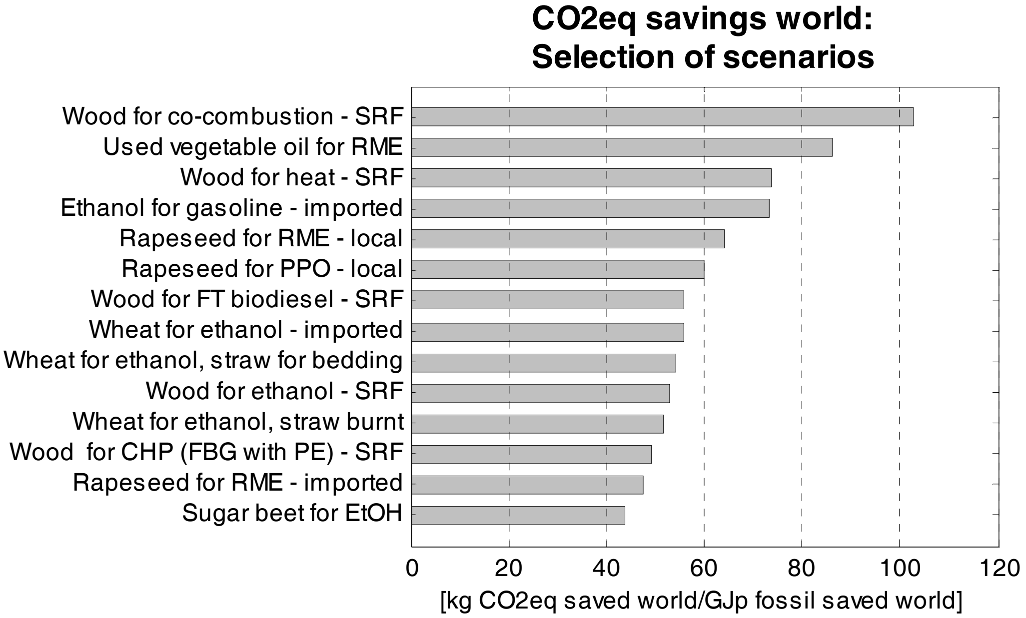

Fig 7 : Global CO2 savings per GJ saved fossil energy, according to SPA.

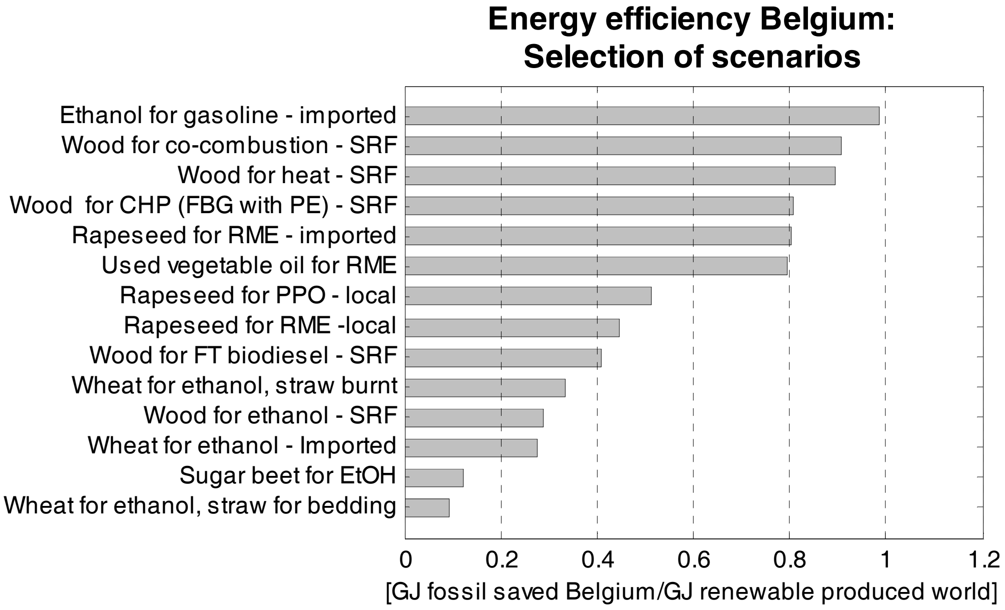

Fig 8 : SPA results for energy efficiency inside Belgium.

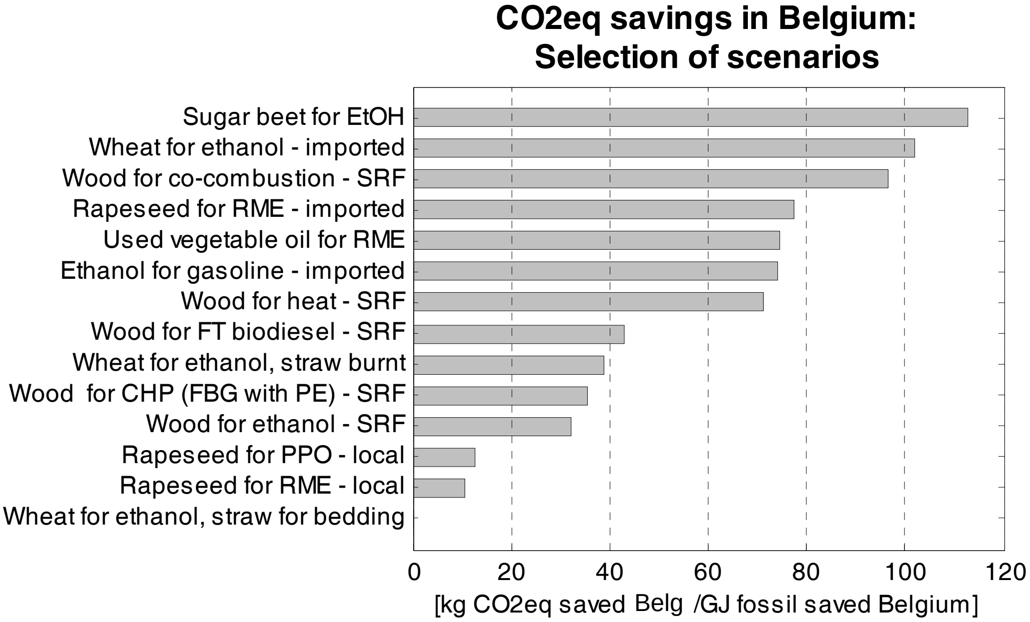

Fig 9 : CO2 savings in Belgium per saved fossil energy, according to SPA.

Figures 8 and 9 show the same type of results but taking Belgium as system border. Figure 8 now compares the net fossil energy savings crossing the Belgian border against the gross biomass energy produced and/or imported. Efficiencies are almost all reduced when compared with the global results in Figure 6 : they now range from a poor 10% to attractive values exceeding 90%. This high disparity and rather strong reduction are due to the fact that Belgium is a net importer of electricity, wheat, rapeseed and animal feed : much of the corresponding utility energy is spent outside of the system and the efficiencies are therefore lower when compared to LCA or global

SPA analysis. Similar conclusions are drawn for CO2 in Figure 9, where all scenarios yield CO2 savings ranging from very poor to high. The import scenarios show high CO2 savings because the CO2 cost is outside whilst the benefit is inside! This is a perverse effect which should be compensated by the CO2 emission trading costs. The CO2 savings show on the contrary pretty low values for rapeseed and wheat due to a combined effect of high N2O emissions from the land and net import of animal feed in Belgium. Sugar beat has a better CO2 saving per GJ fossil saved but it is due to the low efficiency rather than large savings.

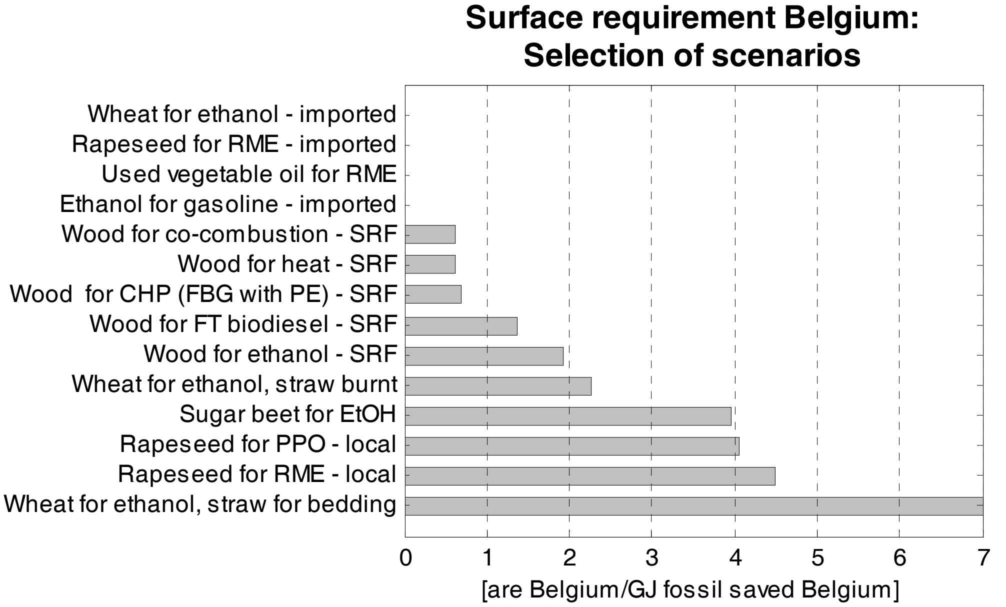

Fig 10 : Required arable surface per saved GJ of energy in Belgium, according to SPA.

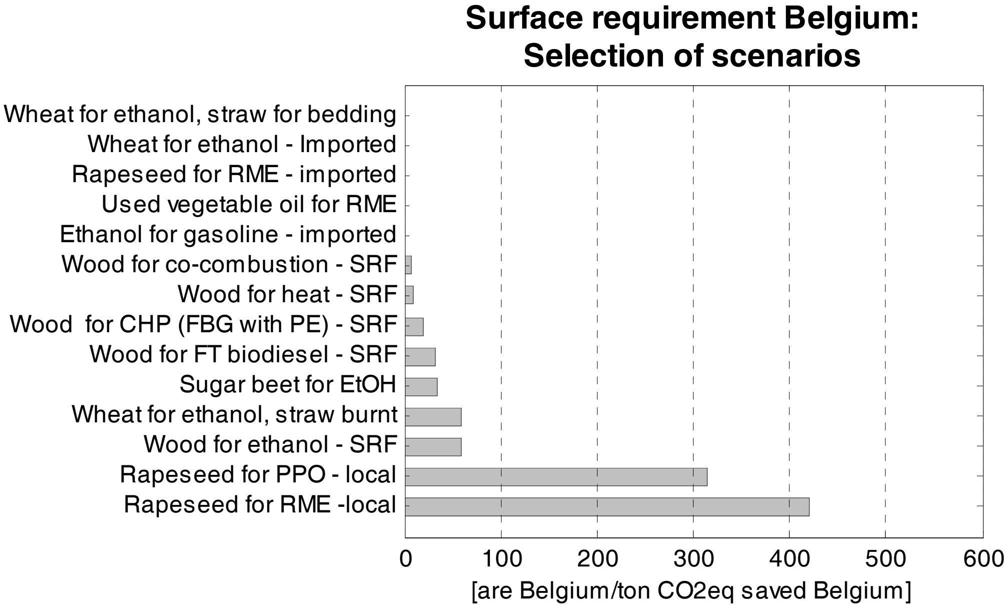

Fig 11 : Required arable surface per saved ton CO2 in Belgium, according to SPA.

Figures 10 and 11 show the corresponding surfaces required for net fossil energy and CO2 savings inside Belgium, which is not unimportant in terms of limited availability of land. Figure 10 shows the required area per saved fossil GJ, whereas Figure 11 shows the required area per saved ton of CO2eq. 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.

CONCLUSIONS

It is shown that the possible available arable and forest land for energy applications can cover no more than a few percentages of the overall Belgian energy consumption, which is mainly due to the high energy demand and low land availabilities in Belgium. The biomass availability in Europe and World levels appear to be more promising and increasing biomass imports are therefore to be expected.

Overall energy and CO2 balances are in general positive to very positive, provided all by-products and secondary effects are taken into account. When limiting these balances to the Belgian system, local effects such as reduced imports of by-products or electric power may lead to different conclusions, mainly in terms of CO2 for the use of local wheat for ethanol. It must certainly further be investigated how the animal feed, wheat and electric power markets are really disturbed by the introduction of biofuels.

The use of wood appears as a good choice in terms of efficiency, CO2 abatement and surface requirements. Short rotation forestry is however far from being currently applied, and wheat, rapeseed and sugar beet for non-food applications must be used to reach the targets set by the EU. It is however believed that on the long term, energy from woody biomass can become the primary resource.