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LAND USE REQUIREMENTS OF DIFFERENT EU BIOFUEL SCENARIOS IN 2020

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Content

Abstract

This study analysis the amount of land required to produce 10% biofuels for the EU in 2020. The study has been undertaken as part of a larger review commissioned by the UK government on the sustainability and direct and indirect effects of such a 10% target.

Total gross land requirements, without compensating for co-products, for a 10% target vary between 16.5 and 31.5 Mha depending on the feedstock mix used. Focusing on feedstocks with a better GHG-performance as well as increasing the amount of second generation biofuels from residues both decrease the gross land requirements.

However, many first generation biofuel chains also produce co-products such as rapeseed meal or DDGS. When these products are used as animal feed they displace other products. This reduces the land requirements for the production of these substituted products.

Because of the large effects of co-product, based on CE (2008), the net land requirements, after compensating for co-products, are up to 62% smaller than the gross land requirements. Strangely enough the net land requirements of the GHG-based scenarios are higher than that of the volume-based scenarios. This is caused by the higher shares of wheat, maize, oilseed rape in the volume-based scenarios that yield more co-products than sugar cane, oil palm and Jatropha (important feedstocks in the GHG bases scenarios). Based on CE (2008) their net land requirement per toe of biofuel including co-products is lower.

Furthermore we find that first generation energy crops such as oil palm and sugar cane have a higher biofuel yield per hectare than woody and herbaceous crops used for lingo-cellulosic biofuels. If co-products are taken into account, also other first generation crops such as rapeseed and wheat have a higher biofuel yield than woody and herbaceous crops. Second generation biofuels from residues do not put direct pressure on land use change. However, EU residues are insufficient to meet the demand for electricity and heat in a 20% renewable energy scenario. Biofuels will thus have to compete with the heat and electricity sector for these residues and residue imports may be required.

In terms of land use *change* we find that in all scenarios more than half the land requirements for biofuels are expected to cause a land use change outside the EU – even if the majority of biofuel feedstocks are cultivated within the EU because these feedstocks displace significant amounts of EU-exports.

We indicate several reasons why it is hard to estimate the exact amount of indirect land use change as a result of such displacement effects. Nonetheless, we also find that little

evidence exists that demand-induced yield increases or other mechanisms will prevent large scale indirect land use change. We therefore currently consider the risk of indirect land use change high.

This study focused on land requirements for biofuel production. Care should be taken when interpreting our findings as minimization of land requirements may not necessarily lead to a minimization of GHG-emissions or even a minimization of land use change. Biofuels that do no not suffer from large risks of indirect land use change are (from Ecofys 2007):

1. Biofuels produced from feedstocks cultivated on idle land.
2. Biofuels produced from residues or other feedstocks that do not require large amounts of agricultural land such as aquatic biomass.
3. Biofuels produced from feedstocks obtained from *additional* yield increases.

1 Overview of EU biofuel scenarios analysed

The proposed 10% biofuel target for the EU can be realised in different ways. The land requirements for this target and the resulting land use change can therefore vary significantly. For this reason, different scenarios have been defined that differ on aspects such as the emphasis on greenhouse gas (GHG)-emission savings and the role of second generation biofuels.

Four basic scenarios are analysed in which the role of second generation and the stimulation of GHG-emission savings is varied. In addition several what-if scenarios are included to analyse the effects of changes in other important parameters such as the size of the biofuel target and agricultural yields. This will give in insight in the range of likely land requirements and how different ways of achieving the biofuel target will affect these land requirements.

The four basic biofuel scenarios were based on the scenarios defined by E4tech (2008) with agricultural yields from ADAS (2008). The reader is referred to these reports for a more detailed discussion on the choices made in these scenarios.

Changes made to original scenarios

For comparability reasons we made several changes to the E4tech scenarios. These are described in Annex A.

1.1 Basic scenarios

The four basic scenarios are summarised in Table 1-1 and Figure 1-1.

Table 1-1 Basic scenarios for a 10% biofuel target by energy content for the EU-27 in 2020.

	Low 2nd generation (0%)	**High 2nd generation (30-34%)**
Volume target (10% by energy content)	Scenario 1	Scenario 2 (30%)
GHG target (with equivalent volume as volume target)	Scenario 3	Scenario 4 (34%)

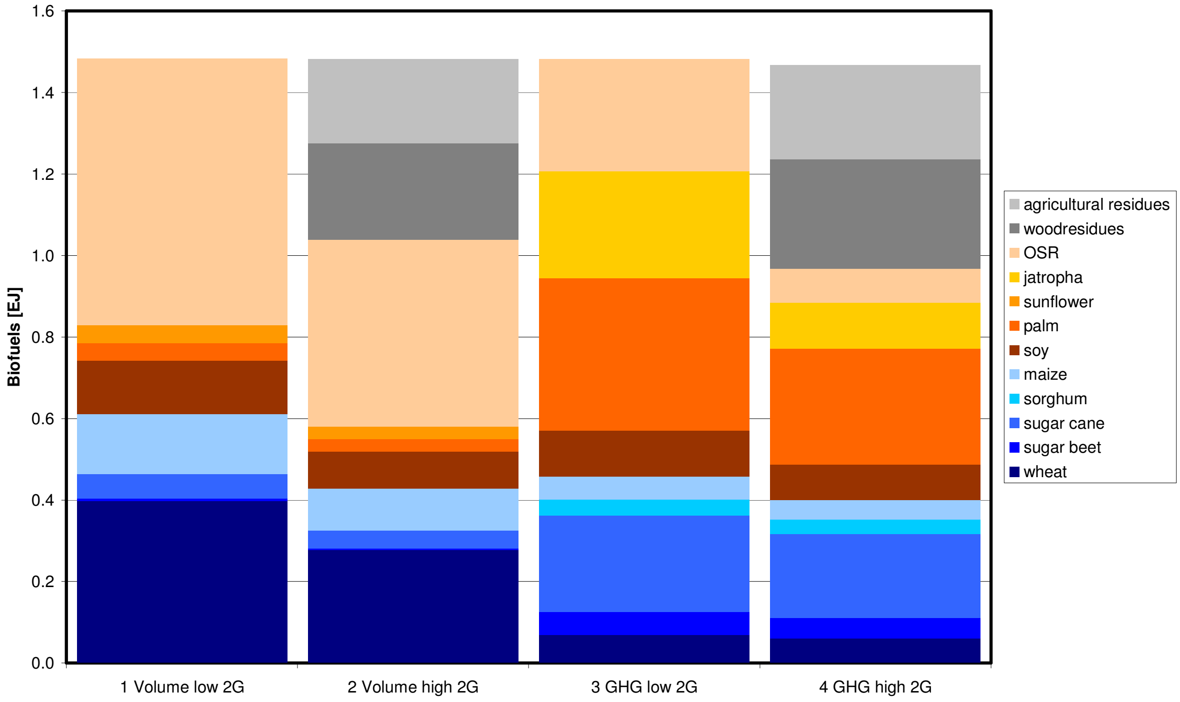

Figure 1-1 Contribution of different feedstocks in total biofuel production in different scenarios. Total biofuel production (based on energy content) has been kept constant between the scenarios for comparability.

Feedstock mixes are inputs to our analysis and are not model outcomes. The main observation is that changing the biofuel target from a volume-based to a GHG-savings-based target results in higher shares of good carbon-performing crops such as sugar cane, palm oil and jatropha and a decline in share of crops such as oilseed rape (OSR) and wheat. The contribution of sugar beet is higher in the GHG savings targets, whereas the share of sunflower is completely diminished.

The share of second generation biofuels amounts to 30% in the volume bases scenario (2) and 34% in the GHG-based scenario (4) – because of the extra impetus GHG targets would give to second generation fuels. All second generation biofuels are assumed to be produced from residues – having zero land requirements.

1.2 Alternative scenarios

In addition to the above four basic scenarios, additional scenarios have been included to analyse the effect of different yield developments and different biofuel targets.

Lower volume targets

- 5.75% and 7% biofuel target by energy content
    - using the same feedstock mix as in scenario 1 (10% biofuel target with low second generation contribution).

- using the same feedstock mix as in scenario 2 (10% biofuel target with high second generation contribution).
- using the same feedstock mix as the 2010 scenario taken form E4tech (2008). This scenario has a feedstock mix that is very similar to the current feedstock used in the EU.

Higher and lower yields

- Low yields prediction for 2020 from ADAS (2008), combined with scenario 1 feedstock mix.
- High yields prediction for 2020 from ADAS (2008), combined with scenario 1 feedstock mix.

1.3 Yields

Land requirements depend critically on the yield of the agricultural commodity which delivers the biofuel feedstock (e.g. rapeseed or sugar cane) as well as the conversion efficiency of this agricultural commodity to biofuels.

- Yields of agricultural commodities used for first generation biofuel production are taken from the Business As Usual scenario for 2020 from ADAS (2008)
- Agricultural yields of woody crops and grasses are taken from EEA (2007).
- Conversion efficiencies and energy contents of both first and second generation biofuels are taken from E4tech (2008).

The resulting biofuel yield per hectare for the different feedstocks is shown in Figure 1-2. Biofuel yields have been expressed in tonnes of oil equivalent (toe) to compensate for the difference in energy content of the different biofuels. For more information on yields, the reader is referred to ADAS (2008).

High biofuel yields can be observed especially for sugar cane, sugar beet and palm oil. These crops have higher biofuel yields than second generation energy crops.

The biofuel yield for soy is relatively low, but its co-products can significantly increase yields and lower land requirements (see Section 1.2). In general, ethanol feedstock yields are higher than biodiesel feedstock yields (taking into account biodiesel's higher energy content).

Yields of second generation energy crops show large ranges, in which second generation syndiesel production is less efficient than second generation lignocellulosic ethanol due to its lower conversion efficiency[1]. Woody crops have lower yields than grassy crops.

[1] The higher energy content of syndiesel has been taken into account.

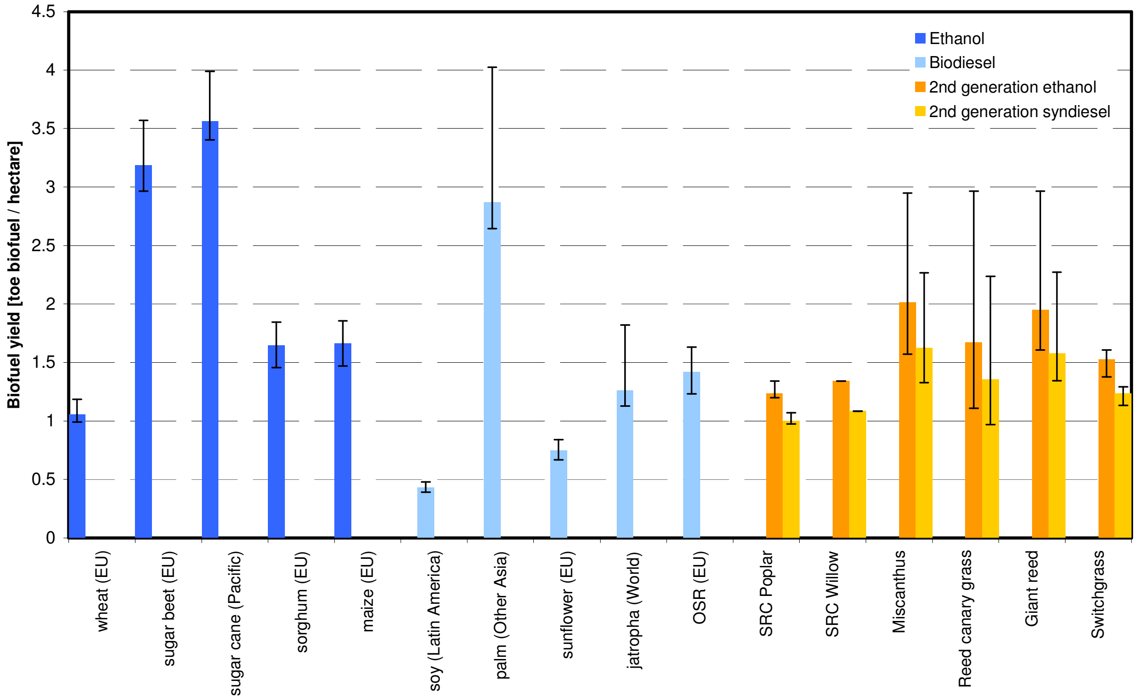

Figure 1-2 Biofuel yield per hectare for different biofuel feedstocks used in the scenarios. The bars show the expected yield in 2020 while the range indicates the difference between the low and high yield predictions as given by ADAS (2008). These yields do not include any compensation for useful by-products or additional biofuel production from agricultural residues - these are discussed in section 1.4.

1.4 Biofuel co-products reduce land requirements

The feedstocks from which biofuels are produced typically yield one or more co-products in addition to biofuels. For example, the production of biodiesel from rapeseed also generations rapeseed meal and the production of ethanol from wheat also generates distillers grains.

The production of co-products is taken into account in the land requirements for biofuels, using CE (2008). CE (2008) uses a substitution approach for the following crops: rapeseed, wheat and maize. An analysis was made of what products the co-products of these feedstocks are likely to replace and how much land would have been required to produce these replaced products. An example of this calculation is given in Box 1-1.

For biodiesel from soy, soybean meal is the main co-product. This is dealt with through economic allocation in CE (2008). Co-products of other feedstocks were not included in the analysis of CE (2008) - see CE (2008) for more details.

The results in terms of the hectares of land required to produce one toe of biofuel excluding and including compensation for co-products is shown in Figure 1-3. This figure also shows what happens to the land required to produce one toe of biofuel from different energy crops if the straw is used for ethanol production. To calculate the amount of residues that are sustainably available for ethanol production for the different energy crops we used residue-to-product ratios from Refuel (2008) and assumed only 63% of these residues can be used sustainably, based on EEA (2007).

Box 1-1 Example of how co-products compensate part of the land requirements for biofuels.

With an expected rapeseed yield of 3.9 tonnes of rapeseed per hectare in 2020 and taking into account conversion efficiencies, one tonne of biodiesel from rapeseed would require 0.61 ha of land. However, rapeseed used for biodiesel also yields 1.35 tonnes of rapeseed meal for each tonne of biodiesel. CE (2008) concludes that this 1.35 tonne of rapeseed meal replaces 0.97 tonne of soybean meal and 0.31 tonne of maize as animal feed. The land that would have been needed to produce this maize and soybean meal equals 0.44 ha.

Because less soybeans are produced because of the substitution, also less soy oil is produced and this still needs to be accounted for. CE (2008) concludes that this will be substituted by additional palm oil production which results in an additional land requirement of 0.05 ha per tonne of biodiesel from rapeseed. Furthermore CE (2008) ignores the co-products generated in palm oil production because of the relative modest quantities of co-products in palm oil production.

The net avoided land use resulting from the co-products of rapeseed production thus amount to 0.44-0.05 = 0.40 hectares per tonne of biodiesel from rapeseed.

The net land requirement to produce one tonne of biodiesel from rapeseed is therefore 0.61 – 0.40 = 0.21 hectares: a significant reduction in land use is achieved through the by-products.

Figure 1-3 below shows that especially the land requirements of soy biodiesel are significantly lowered by its co-products, since soy yields much more meal than oil. The utilisation of the agricultural residues reduces land requirements per toe biofuel even more. Wheat shows a large decline as well, which can be mainly attributed to the land use avoidance of the distillers grains.

For second generation energy crops no co-products are produced and all of the feedstock is utilized for biofuel production. The figure shows that almost all first generation crops outperform the second generation energy crops, if co-products and straw utilization are considered. For sorghum, Jatropha and palm insufficient data was available to derive utilization ratios for agricultural residues.

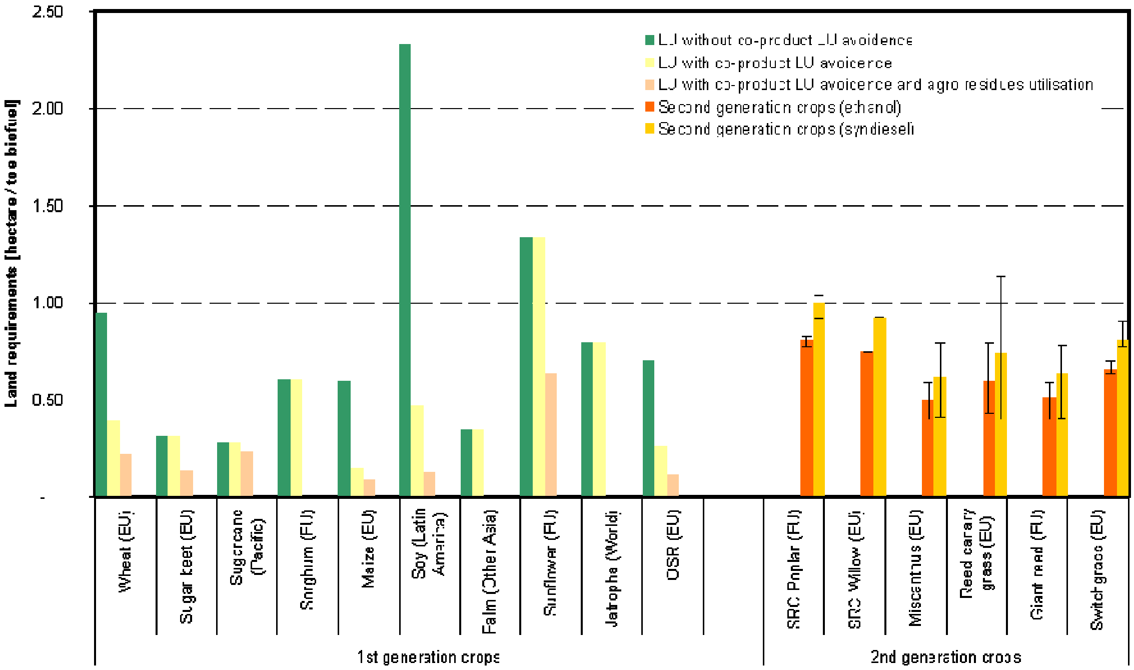

Figure 1-3 Hectares required to produce one tonne of oil equivalent of biofuel from different feedstocks. For each feedstock the left bar indicates the hectares required if co-products are not taken into account. The middle bar indicates the hectares required in co-products are taken into account. The third columns shows the hectares required if also the straw is used to produce ethanol, which further reduces the land requirements.

Conclusion: co-products have a significant impact on land use requirements for biofuels

As can be seen from Figure 1-3, compensating for co-products in line with CE (2008) has a significant impact on the land requirements of biofuels from first generation energy crops. For rapeseed, soy, wheat and maize the land requirements per tonne of biofuel are reduced by 60-81%.

Because of the large impact of co-products on the land requirements of biofuels, further research in this area is recommended.

1.5 Residue potential and competition with other uses

1.5.1 Is the residue potential sufficient for biofuels, heat and electricity demand?

Sustainable EU residue potential in 2020

The sustainable residue potential in the EU-25 is analysed in a study by EEA (2007): "How much bioenergy can Europe produce without harming the environment?" The results of this study, covering the sustainable residue potential in the EU-25 in 2020 are summarized in Figure 1-4. The total residue potential amounts to 116 Mtoe.

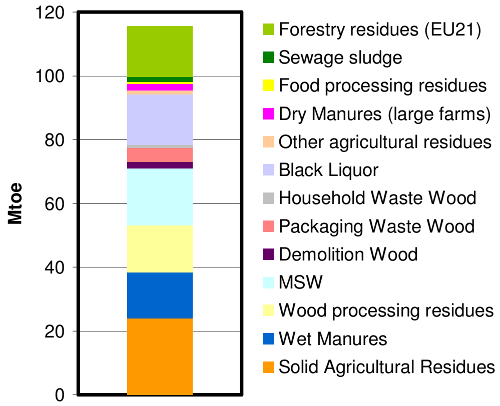

Figure 1-4 Sustainable residue potential in EU-25 in 2020. Source: AEA Technology 2008 and EEA 2007.

Biomass demand from heat and electricity sector

The heat and electricity production from biomass under a 20% renewable energy scenario is analyzed in the renewable energy roadmap which results in a total electricity production from biomass of 1.10 EJ and a total heat production from biomass of 3.81 EJ. With rough assumptions on the conversion efficiency this translates into a biomass demand for heat and electricity in the EU-25 in 2020 of almost 180 Mtoe or almost 65 Mtoe more than the sustainable residue potential in the EU-25, see Table 1-2.

Table 1-2 Biomass needed for electricity and heat production under a 20% renewable energy scenario in the EU-25 in 2020. Electricity and heat production (output) from biomass is taken from the Renewable Energy Roadmap. Simple assumptions were made on conversion efficiencies. RES-E stands for renewable energy supply – electricity. RES-H stands for renewable energy supply – heat.

	Output (EJ)	Conversion efficiency (assumed)	Required biomass input (Mtoe)
RES-E	1.10	40%	66
RES-H	3.81	80%	113
RES-E + RES-H	4.91		179

Conclusion

The EU-residue potential alone is not enough to supply the biomass needed for heat and electricity production as predicted in the Renewable Energy Roadmap for the EU-25 in 2020 with a 20% renewable energy target. This means that also without biofuel production from residues, the heat and electricity sector will need to source biomass from alternative sources such as imported residues or energy crops.

In the biofuel scenarios analysed here, it is assumed that all second generation biofuels is produced from residues. This would form a competition for biomass with the heat and power sector and would require these sectors to source a larger share of their biomass from either imported residues or energy crops.

1.5.2 Residues for first generation fuels

First generation biofuel production from residues is mainly limited to using animal fats and recycled fats for biodiesel production. The potential of animal fats and recycled fats in 2020 has been calculated in the VIEWLS project (Eibensteiner, 2001). The 2020 projection is based on an availability of 5 kg per capita. This results in 90 PJ of available animal fats and recycled fats in the EU-27, based on a LHV of 36.9 GJ/t.

Given the conversion efficiency of 0.875 $ton_{biodiesel}$ / $ton_{feedstock\ (tallow)}$ (E4Tech, 2008), this translates into 2.4 billion litres of first generation biodiesel that could be supplied by residues. In a 10% volume target, this equates to 9.1% of the biodiesel demand in 2020 or 5.4% of total biofuel demand within the EU-27.

Biofuel production from residues results in lower land requirements since any biofuel produced from residues can be subtracted from the total biofuel produced from energy crops. However it should be noted that many residues are already have productive functions in other industries. Using such by-products for biofuel may lead to negative consequences from displacement effects. For a study on the displacement effects of using tallow for biodiesel see Howes (2008).

Residues for first generation biofuels have not been taken into account in the scenarios of E4Tech due to the lack of sufficient data for other regions. This means that the calculated land requirements in this study are higher than if first generation biofuels from residues were to be taken into account.

2 EU biofuel land requirements

The land requirements of the different scenarios are summarised below.

2.1 Basic scenarios

Figure 2-1 shows the land requirements of the four basic scenarios. This is firstly shown in the contribution that each of the feedstocks has on total *gross* land requirements. Secondly, the avoided land use of the co-products (see graph 1.3) has been taken into account. The resulting *net total* land requirement is displayed in the grey bars on the right of each scenario.

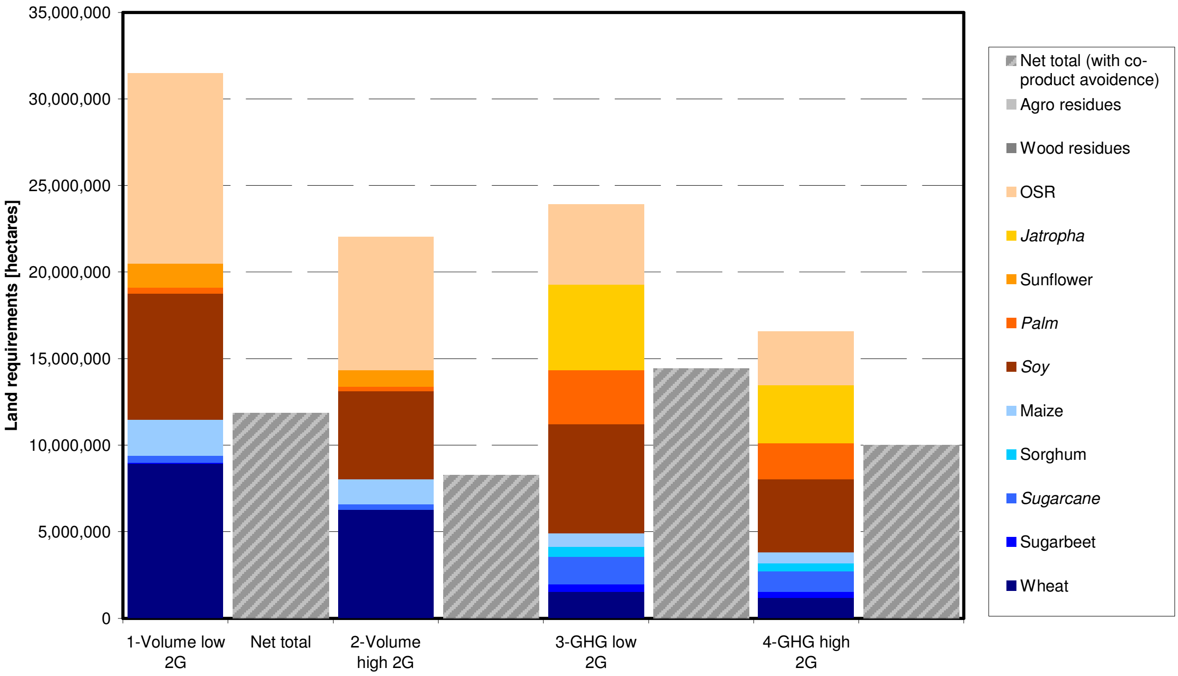

Figure 2-1 Land requirement for different biofuel scenarios. Both the gross land requirement is shown (without compensation for co-products) and the net land requirement (with compensation for co-products). Biofuels produced from residues do not require land and therefore do not show up in these results.

A volume-based target with no second generation contribution results in the highest claim for land (i.e. 31.5 Mha), of which a large share of the land is being used for OSR, soy and wheat. If the avoided land of co-products is included, the total land requirements are reduced to 11.9 Mha for scenario 1. High contribution of second generation biofuels in a volume-based target (scenario 2) results in 30% reduced land requirements (equal to the share of second generation biofuels as these are assumed to be produced from residues only).

The GHG-based-target scenarios (scenario 3 and 4) result in lower gross land requirements than the volume-based-target scenarios. With fixed volumes, a GHG-based target would result in a 25% lower gross land requirements. However, a striking result is that the net land requirements of the GHG-based scenarios are higher than of the volume-based scenarios. This is mainly caused by the higher shares of wheat, maize, OSR in the volume-based scenarios. These crops yield more co-products than sugar cane, oil palm and Jatropha (important feedstocks in the GHG bases scenarios) and based on CE (2008) their net land requirement per toe of biofuel including co-products is lower: see Figure 1-3.

2.2 Alternative scenarios

Yields

The effect of different agricultural yields in 2020 are shown in Figure 2-2, in which three sets of yields from ADAS (2008) have been used: low yields (projected yields for 2010), business-as-usual yields and high yields (maximum improvement yield projections). It shows that for the volume-based scenarios, low yields results in 11% more land requirements and higher yields result in 12% less land requirements than the business-as-usual case. For the GHG-based scenarios, low yield result in 11% more land required and high yields lead to 18% less land required than the business-as-usual case.

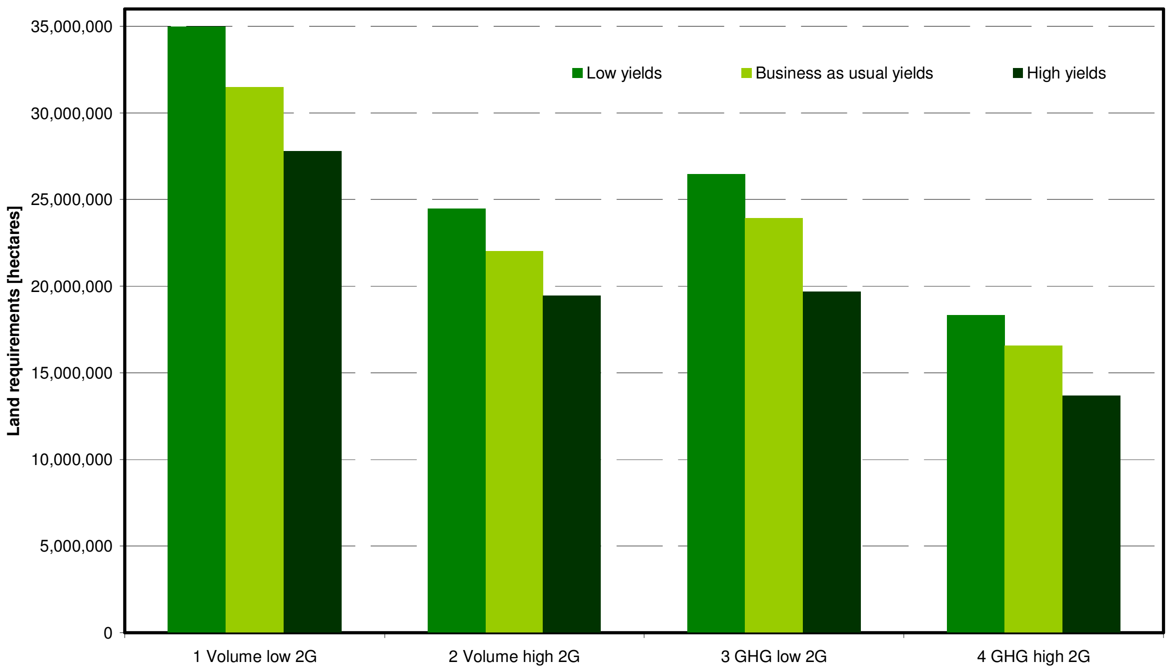

Figure 2-2 Land requirements of the four basic scenarios using low, BAU and high agricultural yield projections.

Lower targets

Figure 2-1 shows the impact of lower targets (5.75%, 7% and base case 10%) on land requirements. This has been assessed for two feedstock mixes, one being the 'volume-based, no second generation feedstock mix' and the other being the 'volume-based, high second generation feedstock mix'. Because the feedstock mix has been assumed to be the same for lower volume targets as for the 10% target, the land requirements are proportionally less. In reality, lower targets might lead to a feedstock mix with fewer imports or lower second generation biofuel contribution. This would clearly have an effect on land use, but has not been studied here.

Another interesting observation from Figure 2-3 is that both the gross and net land requirements of a 10% target with high second generation biofuels (30%) is lower than a 7.5% target without second generation biofuels. This is mainly because second generation biofuels are produced from residues in these scenarios, which greatly reduces land requirements.

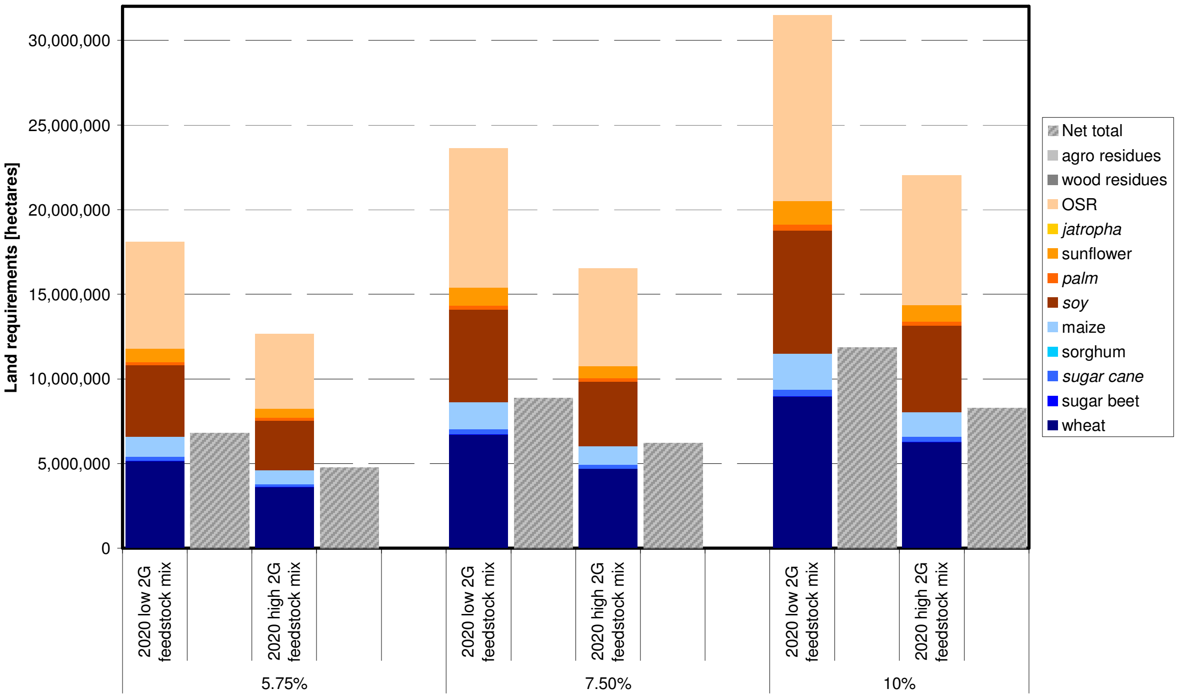

Figure 2-3 Gross and net land requirements of different biofuel targets.

3 Biofuel induced Land Use Change

3.1 Gross land requirements and land use change

The results discussed in the previous section give an insight into the land requirements for the different biofuel scenarios. An important question is what land use *change* (LUC) can be expected from this land requirement. For this purpose we have divided the total land use (LU) into four categories which each have their own effect on land use change. The land use categories we use are based on the categories used in the Annex to the EU Biofuel progress report which analyses the land requirements of a 7% and 14% biofuel target in the EU-25 in 2020 (EU 2007):

- Land requirements within the EU
    - Area taken out of set-aside in the EU: this leads to a LUC within the EU from set-aside land to cropland. In the biofuel progress report it is concluded that 40% of the land use for biofuels in the EU falls within this category.
    - Additional area kept in production in the EU: this is land that would have fallen out of production if no biofuel feedstocks were produced. This too leads to a LUC within the EU from set-aside land to cropland. In the biofuel progress report it is concluded that 22% of the land use for biofuels in the EU falls within this category.
    - Area re-oriented from exports to domestic feedstock production. This leads to an indirect LUC outside the EU as the products which used to be produced in the EU will now have to be produced somewhere else. In the biofuel progress report it is concluded that 37% of the land use for biofuels in the EU falls within this category.
- Land requirements outside EU
    - Imports, being either biofuels or biofuel feedstocks. This leads to a direct or indirect LUC outside the EU.

Using the above land use categories the *gross* land requirements (without compensation for co-products) of can be divided into:

- land requirements causing land use change within the EU and;
- land requirements causing LUC outside the EU.

Table 3-1 Gross land requirements (Mha) for biofuels within the EU and outside the EU, and the impacts on LUC within and outside the EU.

	Type and location of Land Use Change caused	Gross land use (Mha) Volume - low 2nd	Volume - high 2nd	GHG - low 2nd	GHG - high 2nd
Within EU: total		23.4	16.4	8.0	5.7
Area taken out of set-aside	Direct LUC in EU: set-aside -> cropland	9.4	6.6	3.2	2.3
Additional area kept in production	Direct LUC in EU: non-arable land -> cropland	5.2	3.6	1.8	1.3
Area re-oriented from exports to domestic biofuel feedstock production	Indirect LUC outside EU: non-arable land -> cropland	8.7	6.1	2.9	2.1
Outside EU (Imports)	(In)direct LUC outside EU: non-arable land -> cropland	8.0	5.6	16.0	10.9
Total LU causing LUC in EU		14.5	10.2	4.9	3.5
Total LU causing LUC outside EU		16.7	11.7	18.9	13.0

3.2 Uncertainty in the amount of indirect land use change

For the category "Area re-oriented from exports to domestic biofuel feedstock production" it can be expected that this will cause a LUC outside the EU but it can not be said how large this LUC outside the EU will be because:

- It is not known what export-crop is replaced in the EU by the biofuel feedstock. This can be the same crop as the biofuel feedstock but can also be different as different crops can be grown on the same land.
- It is now known what crop will substitute the replaced EU-export-crop. For example, displaced EU wheat exports could be substituted by other grains.
- Even if it would be known which crop substitutes the displaced EU-export-crop, it is not known where this substituting crop will be cultivated and what the yield of this crop will be. Therefore the land requirement for the substituting crop is not known.

In line with the above observations it can also be concluded that one displaced hectare in the EU does normally not lead to one hectare of indirect LUC outside the EU. The following examples illustrate this point:

- If one hectare of wheat is displaced in the EU and is substituted by the same crop in a country outside the EU, the amount of land required for this in that country depends on its wheat yield compared to the wheat yield in the EU. If the yield in the country in which the indirect LUC takes place is half that of the EU, it will need twice as much land as in the EU to substitute the same amount of wheat. (It is not concluded here that there is a one to one relationship between the amount of displaced product and the amount of substituting product).
- If the EU diverts more rapeseed oil production from food to feed than it increases its production of rapeseed oil it is likely to increase its imports of vegetable oils. This could be rapeseed oil but could also be a different vegetable oil as different vegetable oils are to some degree substituting products. Thoenes (2007) states that "EU palm oil imports have already doubled during the 2000-2006 period, mostly to substitute for

rapeseed oil diverted from food to fuel uses." As the yields of different vegetable oils vary significantly, the amount of land required to substitute for the displaced rapeseed oil depends on the substituting oil. This equation is further complicated by the different types and amounts of co-products generated by different vegetable oil crops.

In summary, the amount of indirect LUC based on a given amount of displaced land use in the EU is very difficult to determine. For this reason we present our results as the amount of land used for biofuel feedstock production which causes *a* LUC outside the EU, without specifying how *large* this indirect LUC will be.

Other aspects add to the uncertainties on indirect LUC. As discussed in our accompanying paper on the impact assessment of the EU on the 10% biofuel target, price induced yield increases appear unlikely to prevent indirect LUC as argued by some. Other well documented reasons why significant indirect LUC will *not* occur are not known to us. We therefore consider the *risk* of indirect LUC significant although we can not say how large such indirect LUC will be.

3.3 Avoided land use change from useful co-products

As discussed in section 1.4, co-product generation can have a significant impact on the amount of net land needed for biofuels. Using the type and amount of substituted products from CE (2008) we estimated the total avoided LUC from co-products. We have split this into avoided LU within the EU (if the substituted product is grown within the EU) and avoided LU outside the EU (if the substituted product is grown outside the EU. For avoided LU in the EU we have used the same division into the different categories as for the gross land requirements for biofuel feedstock production in the EU. The results are shown in Table 3-2.

Table 3-2 Avoided LU (Mha) from co-products within the EU and outside the EU, and its impacts on LUC within and outside the EU.

		Avoided LU			
	Type and location of Land Use Change prevented	**Volume - low 2nd**	**Volume - high 2nd**	**GHG - low 2nd**	**GHG - high 2nd**
Within EU: total		2.2	1.5	0.6	0.5
Area taken out of set-aside	Direct LUC in EU: set-aside -> cropland	0.9	0.6	0.3	0.2
Additional area kept in production	Direct LUC in EU: non-arable land -> cropland	0.5	0.3	0.1	0.1
Area re-oriented from exports to domestic biofuel feedstock production	Indirect LUC outside EU: non arable land -> cropland	0.8	0.6	0.2	0.2
Outside EU (Imports)	(In)direct LUC outside EU: non-arable land -> cropland	17.5	12.2	8.9	6.1
Total avoided LU avoiding LUC in EU		1.3	0.9	0.4	0.3
Total avoided LU avoiding LUC outside EU		18.3	12.8	9.1	6.2

A striking result from the results is that the fast majority of the avoided LUC lays outside the EU. The reason for this is that the main substituted product is assumed to be soybean meal from outside the EU (CE 2008). Most co-products therefore lead to a reduced soybean meal production which causes a reduced land requirement for soybean production outside the EU.

3.4 Net land use and land use change

Combining the gross LU with the avoided LU from co-products leads to the net LU and the accompanying land use change, see Table 3-3.

Table 3-3 Total net LU causing a LUC inside and outside the EU (Mha).

	Volume - low 2nd	Volume - high 2nd	GHG - low 2nd	GHG - high 2nd
Total net LU causing LUC in EU	13.2	9.2	4.5	3.2
Total net LU causing LUC outside EU	-1.5	-1.1	9.8	6.7

Because of the large impact of co-products on LU in this analysis, the net LU causing a LUC outside the EU is negative in the volume-based scenarios. This is not the case in the GHG bases scenarios because 1) these scenarios use more imported feedstocks (Jatropha, palm oil and sugar cane), and 2) these feedstocks produce fewer co-product – which have not been taken into account CE (2008).

The numbers of this analysis should be interpreted with great caution for at least two reasons:

- The type and the amount of products substituted by biofuel co-products have a large impact on the results and there will always be uncertainties in estimating these parameters.
- The avoided LU cancels out a large part of the gross LU in this scenario. However, in terms of LUC, the avoided LU may well take place in a very different area than the gross LU for biofuel feedstocks. This means that still the total gross LU for biofuel feedstocks may cause a LUC while at the same time, but in a different area, land is taken out of production as a result of the avoided LU. Clearly, the effects on issues such as carbon stocks and biodiversity are very different if these two effects take place in different areas than when they would take place in the same area.

A more general point that can be concluded from the above analysis is that *if* substituted products are indeed produced outside the EU, producing biofuel from European feedstocks that generate a lot of co-products, may actually reduce pressure on land use outside the EU. For biofuel feedstocks that produce less co-products, such as second generation crops, this effect will not occur.

4 Conclusions

4.1 Land requirements

Amount of land required for a 10% biofuel target

The gross land requirements (not taking into account avoided LU from co-products) for the four analysed scenarios for a 10% biofuel target range from 16.5 Mha to 31.5 Mha. The large range illustrates the large impact of different feedstock mixes on the total land requirements, keeping total biofuel production equal.

Co-products have a large impact on land requirements

Several biofuel feedstocks generate useful co-products in addition to biofuels such as rapeseed meal and distillers grains. These co-products can substitute other agricultural products, thereby avoiding the land requirements for the production of these substituted products. The type and amount of products replaced by the biofuel co-products were taken from CE (2008). Taking into account avoided land use from co-products results in significant reductions in the net land requirements for biofuels: from 31.5 to 11.9 Mha: a reduction of 62%.

For the GHG-based scenarios these co-products have a smaller impact as the GHG-based scenario is dominated by biofuel feedstocks that generate fewer co-products.

Imports or domestic production: impact on land use

Looking at gross biofuel yields within the EU and outside the EU, it appear that crops grown outside the EU such as oil palm and sugar cane have significant higher biofuel yields than most EU grown crops such as rapeseed and wheat although sugar beet too has a high biofuel yield per hectare. However, the picture changes dramatically if co-products are included in the analysis. Taking into account the avoided land requirement from biofuel co-products according to CE (2008) makes rapeseed yield more biofuel per hectare than oil palm and maize now outperforms sugar cane. This once again shows the importance of co-products. It should be noted here that co-products from palm oil and sugar cane were not taken into account in CE (2008) but the impact of this will be limited due to the limited amount of co-products of these crops[2].

Volume target or GHG target: impact on land use

A GHG-based target implies a more prominent role in the total feedstock mix for those feedstocks that achieve a good GHG performance such as oil palm, Jatropha, sugar cane and residues. These crops typically have a higher gross biofuel yield than the current dominant biofuel feedstocks used in the EU such as rapeseed and wheat, although

[2] With co-products we mean valuable products such as rapeseed meal and distillers grains. It does not include agricultural residues such as straw and bagasse. Bagasse can increase the biofuel yield of sugar cane by converting it to ethanol, but in the same way the biofuel yield of crops such as maize and wheat be increased by using the straw of these crops.

Jatropha yields are expected to be relatively modest (ADAS 2008). However, the picture again changes dramatically if co-products are taken into account. The dominant feedstocks in the volume-based scenarios generate more co-products than the feedstocks in the GHG-based scenario. In this analysis this has resulted in an actual *lower* net land requirement for the volume-based targets than the GHG-based targets.

Note that the conclusions on net land requirement do not permit conclusions on the land use change that will take place or the associated GHG-emissions from this land use change. Conclusions on land use change and emissions from land use change are included below.

Biofuels from residues prevent risks of LUC

Residues do not require additional land for their production and therefore do not put a pressure on land resources. From a policy perspective stimulating biofuels from residues therefore avoids risks associated with land use change.
However, as shown in our analysis biofuels compete with electricity and heat production for residues as the residue potential in the EU alone is not enough for the projected heat and electricity production from biomass in a 20% renewable energy scenario.
Tallow and recycled fats were not included in the scenarios of this study but the European potential for biodiesel from these residues sources amounts to 90 PJ, enough to produce 5.4% of the total biofuel needed in a 10% biofuels scenario.

Are second generation biofuels less land intensive than first generation biofuels?

As discussed above, second generation biofuel technologies can use a wider range of residues with a much larger potential than first generation biofuel technologies. In that respect second generation technologies *can* reduce land requirements if they use residues. It was shown that biofuels will have to compete with heat and power applications of these residues.

If energy crops are used, the picture changes. As can be seen from Figure 1-3 the hectares required to produce one toe of biofuels is not necessarily lower for woody or herbaceous crops (second generation feedstock) than for first generation crops. Without taking co-products or agricultural residues into account, the more efficient first generation crops such as oil palm, sugar cane and sugar beet give higher biofuel yields per hectare than all second generation crops considered (willow, poplar, miscanthus, reed canary grass, giant reed and switchgrass.) Note that this comparison is not entirely fair as the yields for these second generation crops are for Europe and yields could be higher for more tropical regions - where oil palm and sugar cane are also grown.

If co-products are taken into account as proposed by CE (2008), several mainstream first generation biofuel feedstocks such as rapeseed, maize and wheat also outperform the second generation crops. If also the residues from first generation crops are taken into account for ethanol production, almost all first generation crops outperform the second generation crops in terms of land requirements per tonne of biofuel. Note that this does not mean that first generation crops are better than second generation crops. They do appear to have the potential for a higher biofuel yield per hectare but this does not tell us anything about other important parameters such as GHG-emissions from cultivation including land use change.

The main cause for the low biofuel yield of second generation crops is the relative poor conversion efficiency to biofuel, especially for syndiesel.

In conclusion, second generation technologies can avoid large land requirements for biofuels if they are used to convert residues to biofuels. If dedicated woody or herbaceous crops are grown for second generation biofuels, such fuels do not appear to be less land intensive than first generation fuels and even seem more land intensive if the co-products and agricultural residues from first generation biofuels are taken into account.

Does a lower biofuel target reduce the risks of LUC?

As long as the feedstock mix remains constant, producing less biofuels requires proportionally less land. The question is how a lower biofuel target will impact the feedstock mix. This was not analysed in detail within this study but as a hypothesis lower targets may lead to relatively more domestic production and less second generation biofuels. Especially less second generation biofuels from residues would negatively affect the land requirements per tonne of biofuel.

In general, as long as biofuels are produced from energy crops the nature of the risks does not change with a smaller target. What feedstocks are used and how these are produced is likely to have a large impact on the nature of the sustainability of the biofuel target than the exact height of the biofuel target.

How important are yield developments for future land requirements

Clearly higher future yields reduce the land requirements for a given biofuel target. The high yield predictions from ADAS (2008) decrease land requirements by 12% compared to BAU yields. The low yield predictions from ADAS (2008) increase land requirements by 11%.

What is more important is that changes in future yield developments will not only affect land requirements for biofuels but will also determine land requirements for food and feed production. Thereby future yield developments critically influence the total amount of land available for sustainable biofuel production.

Finally, the yields taken from ADAS (2008) refer to product yields such as rapeseed or wheat. As shown in this report, agricultural residues can greatly enhance the biofuel yield of a crop. In terms of maximising biofuel yield per hectare it is therefore more useful to look at the total biofuel yield per hectare including the yield from agricultural residues. It may be more advantageous to accept lower grain yields if additional straw yields lead to higher total biofuel yields. Also synergies between food and fuel production are possible in which part of the plant is used for food and part for fuel. The point is that efforts on future yield improvements should not be focussed on the yield of the main product only.

Should governments steer on GHG emission savings per hectare?

Some parties have suggested than policies should aim to maximise GHG emission savings per ha. While this has some obvious advantages at first sight there are some important risks of this approach that policy makers should be aware of.

On the positive side, such a approach would stimulate the use of those *crop types* that maximise the GHG-savings per ha. It will also stimulate the use of residues that indeed have no or very limited risks of and use change.

However, the risks of this approach include:

- For a given feedstock type the approach stimulates that the feedstock is grown on the most productive land. Such land will typically already be in production as producers will generally choose to convert the most productive lands first. As explained in this report, the amount of indirect land use change is not so much related to the amount of hectares displaced but by the amount of production displaced. If the most productive oil palm areas are used for biofuels it may require twice as many hectares of oil palm to substitute the displaced oil palm. If the displaced oil palm is substituted by a less productive crop such as sunflowers, it will require even more hectares. In short, steering on maximum greenhouse gas savings per hectare, or maximum biofuel yield per hectare, is likely to lead to severe types of uncontrollable displacement effects. For energy crops, it may be wiser to stimulate the expansion of feedstock production on idle land where both the type and amount of land use change is controllable.
- The approach does not stimulate those sustainable potentials in which biofuel crops are used to regenerate degraded lands. While such potentials have clear benefits from a sustainability point of view, they will generally have lower yields and this should not be penalised. It should be noted here however that a low yield in combination with a positive carbon-stock effect does actually lead to a strong improvement of the GHG-performance of the biofuel that could (partly) compensate for the lower yield.

4.2 From land requirements to land use change

Displacement effects will cause land use change in different areas than where the feedstock is grown

We showed that based on the analysed scenarios and the land types used for biofuel feedstock production in the EU, more than half of the gross land requirements is likely to result in a LUC outside the EU. This is true even in those scenarios where most of the land requirements lay within the EU. This is caused by the fact that a significant part of the feedstock production in the EU is expected to displace exports. The displaced exports will now have to be produced outside the EU, which causes a certain amount of indirect LUC. We are currently not able to say how large this indirect LUC will be.

Co-products could reduce pressure on land requirements outside EU

If the co-products of EU-biofuel feedstocks primarily substitute products that are grown outside the EU, the production of these biofuels could actually reduce pressure on land requirements outside the EU. CE (2008) concludes that most co-products largely displace soy bean meal, which is mainly produced outside the EU. For this reason our analysis finds that the co-products can actually cause a reduction in land requirements outside the EU under a 10% target, even if some of the biofuels are imported.

A crucial remark here is that even if the net land requirements outside the EU are negative, conversion of non-arable land to biofuel feedstock production may still occur because of shifts in the location of agricultural land – land taken out of production because of the co-products substitution effect may be located in different areas than the land taken into production for additional biofuel feedstock production.

4.3 The risk of indirect land use change

How high is the *risk* of indirect LUC?

There are already signs that the re-orientation of rapeseed oil in the EU from food to fuel leads to more palm oil imports for food – a clear example of displacement effects with possible indirect LUC as a result.

Our accompanying paper discusses the potential for price induced yield increases which could prevent (parts of) indirect land use change. We find little evidence for this and neither find well documented evidence for other reasons why significant indirect land use change would not occur.

Due to the lack of evidence that indirect LUC will not occur and the inherent logic of displaced production having to substituted or someone else will have to reduce its consumption, we believe the *risk* of indirect LUC is high. However, due to the many complexities in indirect LUC we are currently not able to give a reliable estimate of how large such indirect LUC will be. As we have shown, it is overly simplistic to assume one hectare displaced causes one hectare of indirect LUC: it can be both much more and much less.

How can indirect LUC be prevented?

As described in Ecofys (2007), the risk of indirect LUC does not exist, or is at least significantly reduced, for the following forms of biofuel production:

1. Biofuel production from residues.
2. Biofuel production on idle land. This does cause a direct LUC but because it does not displace another function it does not cause an indirect LUC. The big advantage is that direct LUC is controllable and can be limited to those areas where effects are sustainable, while the effects of indirect LUC are uncontrollable.
3. Biofuel production from *additional* yield increases, on top of business-as-usual yield increases. Especially in developing countries there is significant potential for yield improvements. The positive effects of which can spill over to food production which would further reduce agricultural land requirements.

4. Biofuel production from aquatic biomass such as algae. Nonetheless, specific sustainability requirements for such production will also need to be taken into account.

4.4 Greenhouse gas emissions from land use change

This report deals in detail with land requirements and land use change. However, measures that reduce land requirements per se may have a negative effect on greenhouse gas emissions and policy makers should be aware of this. While it was not possible within the scope of this study to do a detailed analysis of emissions from land use change, policy makers should be aware of at least the following points - based on the IPCC methodology on emissions from land use and land use change (IPCC 2006):

- In terms of emissions from land use change, conversion from non-arable land to perennial crops generally causes significantly fewer emissions than conversion to annual crops. Conversion to perennial crops may even act as a carbon sink. Even if perennial crops have lower biofuel yields per hectare, they could still bring significant higher GHG-emission savings than annual crops. If not grown with the proper management practices, the emissions from land use from especially annual crops could negate the emission savings from biofuels.
- Converting set-aside land back to cropland also has an impact on carbon stocks and should be taken into account.
- Land use change effects of a biofuel target in 2020 should be derived by comparing LU in 2020 with biofuels with LU in 2020 without biofuels. A mistake that is often made is that the LU in 2020 with biofuels is compared to the LU of today. It is then argued that yield increases will free up land and therefore no LUC occurs. This is not correct because without biofuels the freed up land would have fallen into set-aside and would eventually convert to grassland or forest - the comparison should be made to this reference situation. As said above, also the conversion from set-aside to cropland has a carbon stock effect and such changes should be taken into account.
- GHG-emissions from land use and land use change are strongly affected by management factors such as tillage practices and the addition of organic matter to the soil. Policy measures should take this into account and stimulate those practices that minimize emissions from land use.

5 Discussion on uncertainties

The main uncertainties and areas for future research are summarised below:

- As can be seen from Figure 1-3, compensating for co-products in line with CE (2008) has a significant impact on the land requirements of biofuels from first generation energy crops. For rapeseed, soy, wheat and maize the land requirements per tonne of biofuel are reduced by 60-81%. Because of the large impact of co-products on the land requirements of biofuels, further research in this area is recommended. Two aspects that should be taken into account include:
    - CE (2008) now uses a substitution approach for most products but an economic allocation approach for soy bean meal. For consistency reasons it may be preferable to use one methodology for all feedstocks. In addition it will be useful to know the sensitivity of the outcomes to the chosen approach.
    - The RTFO methodology for GHG-emissions also uses a substitution approach but this approach differs from the approach used in CE (2008). It may be worth considering both approaches and test the sensitivity of the outcomes to the approach taken.
- The feedstock mixes in the scenarios analysed here are based on best expert-estimates. The actual feedstock mix will always be uncertain as it depends on relative market prices of different feedstocks as well as technological developments: both of which are very difficult to predict for the medium to long term. The impact of a change in feedstock can be large because of the differences between the different feedstocks in their gross and net land requirements per toe of biofuel.
- Biofuels from residues avoid additional land requirements and the related risks of land use change. However, our analysis shows that there will be a competition for residues between the heat and power sector and the biofuel sector. This makes the availability of residues for biofuels uncertain and even if biofuels are produced from residues it raises the question whether this pushes the heat and power sector to use more energy crops. More research is needed in this area to understand the impacts on land use of this. In this analysis the maximum contribution of residues was 34% of total biofuel production – which was assumed to have zero land requirements.
- Our analysis of biofuel yields per hectare compared first generation crops with second generation crops. Because yields from second generation crops were not available from ADAS (2008) we used yields from EEA (2007). These are European yields and the comparison with sugar cane and oil palm is therefore not entirely appropriate because of the climatic differences of the different regions in which these crops are grown compared to the EU.
- We used yields from ADAS (2008) based on OECD regions, except for Europe for which we used EU-27 yields. Using yields of different aggregation of countries may give different results. In addition, yields from ADAS (2008) are based on current production areas. Expansion of biofuel feedstock production into other areas may result in yields that are different.

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Annex A Modifications to scenarios

The following modifications were made to the scenarios taken from E4tech (2008):

1. In the original scenarios defined in E4tech (2008) the GHG-based scenarios (scenarios 3 and 4) are based on a 7% GHG reduction target. This leads to a different amount of biofuels produced than in the volume-based target scenarios. Because we want to compare the impact of a GHG-target and a volume-based target on land requirements we have adapted the GHG-scenarios to keep total biofuel production (Mtoe) constant in all scenarios. This makes for a more 'fair' comparison between the scenarios as all scenarios now product an equal amount of biofuels (in terms of energy content).
2. In the original scenarios the biofuel demand in Europe is based on consumption forecast figures in the OECD-Europe region. Because the EU biofuel target would apply to the EU-27, we have in stead used EU-27 consumption forecast numbers (source: AEBIOM (2007): European Biomass Statistics 2007).
3. For feedstock grown in Europe we use EU-27 yields prediction from ADAS (2008) in stead of OECD-Europe yield predictions.
4. In the original scenarios from E4tech (2008) there are differences in the relative feedstock mix of first generation biofuels in the low and high second generation scenarios. For comparability reasons we have kept the relative feedstock mix of first generation biofuels in the high second generation scenarios equal to the low second generation scenarios. Thereby the only difference between these scenarios is the introduction of second generation biofuels and differences in land requirements between these scenarios call be fully attributed to the introduction of second generation biofuels.