Intelligent Energy Europe

Biofuels cost developments in the EU27+ until 2030

Full-chain cost assessment and implications of policy options

REFUEL WP4 final report

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H.M. Londo
S.M. Lensink
E.P. Deurwaarder
A. Wakker

ECN Policy Studies

M.P. de Wit
H.M. Junginger

Copernicus Institute – Utrecht Univeristy

K. Könighofer
G. Jungmeier

Joanneum Research

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Table of contents

Table of contents....4
Executive summary....5
1 Introduction 7
2 General assumptions 8
2.1 Shaping of the model 8
2.1.1 Biofuels included in the analysis....8
2.1.2 Distribution and end use....9
2.1.3 Technological learning in Biotrans 9
2.2 Input data....9
2.2.1 Gasoline and diesel demand 9
2.2.2 Shares and targets for biofuels....10
2.3 Assumptions for the impact assessment....10
3 Biofuel options development in the base cases....12
3.1 The baseline....13
3.2 The moderate case....13
3.3 The high case....13
3.4 Biofuel costs 16
3.5 Key feedstock producing regions....17
3.6 The probability of 2nd generation biofuels break-through 18
3.7 Greenhouse gas impacts 19
3.8 Impacts on security of energy supply....20
4 Analysis and evaluation of additional policy options 21
4.1 The effect of imports....22
4.2 Introducing a CO_2 price in the transportation sector....24
4.3 Introducing an investment subsidy on conversion 25
4.4 Introducing a subsidy on energy crops....26
4.5 Introducing specific targets for gasoline and diesel markets....27
4.6 Introducing significant biomass demand for RES-E/H....30
4.7 Comparison of the costs and GHG impacts of the policy options....33
4.8 Biofuels target per country in stead of an overall EU target 34
4.9 Feedstock trade in stead of biofuel trade....35
5 Sensitivity analysis....36
5.1 Impacts of feedstock potential reduction....36
5.2 Penetration of different biofuels in the Monte Carlo analysis 37
5.3 Changes in import costs 38
6 Conclusions 40
6.1 Specific conclusions for the different analyses....40
6.2 General conclusions....41
6.3 Limitations....41
References 43
Annex 1: Greenhouse gas emission data used in Biotrans 44
Annex 2: Variations in input parameters in the Monte Carlo sensitivity analysis (high case)....45

Executive summary

With the rapid developments in the biofuels domain comes the need for biofuel policies that spur their introduction in a responsible way. The REFUEL project, supported by the EU Intelligent Energy Europe programme, develops a road map for biofuels in the EU27+ up to 2030. This WP4 report shows the results of a full-chain analysis of the costs of different biofuels. Effects of different levels of biofuel target setting were analysed, and also the impact of different additional policy measures, such as the introduction of a CO_2 pricing mechanism and specific subsidies.

In almost all analyses with targets higher than the baseline, 2nd generation biofuels enter the mix sooner or later. The share of these fuels in the mix also strongly determines both the overall costs of biofuels (increasing with increasing share of 2nd generation) and the greenhouse gas emission reductions (also increasing with increasing share of 2nd generation). The ratio between 1st and 2nd generation biofuels can be influenced in roughly three ways:

- Generally, a higher target leads to an increase in the share of 2nd generation biofuels in the mix. This is mainly because low-cost feedstock potential for 1st generation gets exhausted above certain target levels, after which 2nd generation gets introduced.
- Limitation of the feedstock base, e.g. by assuming that part of the potential will be allocated to heat and power generation, also increases the share of 2nd generation biofuels; extension of the feedstock base by imports induces a contrary effect.
- Subsidies and CO_2 pricing mechanisms have impacts according to the differences in greenhouse gas emission profile and cost structure of the different biofuels: investment subsidies and CO_2 pricing enhance 2nd generation biofuels with their high capital costs and high GHG emission reductions, while an energy crop premium per ha enhances 1st generation biofuels with their high feedstock costs.

Furthermore, biofuel costs do not vary very strongly over time, not even when the biofuels target increases strongly. This is due to two countervailing mechanisms: on one hand, an increasing target leads to application of higher parts of the cost-supply curve for biomass feedstock, inducing higher costs. On the other hand, especially 2nd generation conversion technologies reduce costs over time due to technological learning. In many cases these two effects balance each other out almost completely.

A (moderate) specific subtarget for 2nd generation biofuels does not lead to significantly different results in most model runs. Such a subtarget does not seem to be necessary when a high biofuel target, possibly combined with a CO_2 pricing mechanism and ambitious targets for RES-E/H, is in place. On the other hand, the combination with subtargets for gasoline and diesel substitutes shows that there is a significant probability that 2nd generation biofuels do not enter the market; in such a case, a subtarget for 2nd generation biofuels would be a back-up measure to ensure their introduction.

When interpreting the results and conclusions presented here, there are some essential limitations of our approach that should be borne in mind.

- The Biotrans model calculations are based on production costs, for conversion technologies as well as for feedstock. In practice, both will operate in dynamic markets. First, prices resulting from a match between biofuel demand and supply may differ significantly from the average production costs. Furthermore, biofuel feedstocks, which relate to (agricultural) commodity markets, may face significant price volatility due to developments in global feedstock demand for other applications than biofuels, and in supply. Therefore, there may be significant differences between actual prices and the costs calculated here, especially in the short term. These limitations apply to EU-domestic feedstock production as well as imported biofuels and feedstocks.

- The Biotrans model optimizes to a least-cost fuel mix meeting a given demand for biofuels. This leads to quite radical choices between biofuel chains, also when the cost differences between the chains are relatively minor. In reality there will always be niche situations in which costs differ from the average, and investors will have imperfect information, so biofuels with slightly higher production costs will probably be introduced as well. This also implies that the strong dominance of biodiesel in our model outcomes is too simplified: in reality both biodiesel and bio-ethanol are being deployed because both can be competitive in different situations. Furthermore, this limitation applies to the 2nd generation biofuels FT-diesel, lignocellulosic ethanol and DME, whose production costs lie in the same order of magnitude and contain considerable uncertainties. At least, the biofuels market will be sufficiently large to allow the entrance of more than one of these advanced technologies and their subsequent learning-by-upscaling.

- Finally, our analysis has not taken into account any issues related to the integration of biofuels into the current and future EU refinery capacity, and possible mismatches between the gasoline-diesel split in EU supply and demand.

1 Introduction

The attention for biofuels is rapidly growing. Main drivers for this trend are climate change mitigation policy, energy security concerns, and ambitions for sustainable rural development and industrial development. Within the EU, the 2003 Biofuels Directive has been an important milestone; in new renewables directive, a binding target of minimally 10% is expected to be in place.

With this development comes the need for biofuel policies that spur their introduction in a responsible way. The REFUEL project, supported by the EU's Intelligent Energy Europe programme, develops a road map for biofuels in the EU27+ up to 2030. The project contains extensive analysis of biomass feedstock potentials in Europe, feedstock costs, biofuel chain analysis and impact assessment. Furthermore, the interrelations with biomass use in the stationary sector for power and heat are analysed, implementation barriers are surveyed and policy options are evaluated. The focus is on the EU27, Norway, Switzerland and Ukraine. The latter is particularly relevant because of its substantial feedstock potential.

This WP4 report shows the results of the full-chain analysis of the costs of different biofuels. Core is the Biotrans model, in which a least-cost mix of biofuels can be calculated over time, as a function of the costs of different biofuels. This model was developed and applied in the VIEWLS project (Wakker et al., 2005), and has been extended and updated for this project. For example, the model now takes into account technological learning in a more sophisticated manner, and also directly calculates the greenhouse gas emission reductions of the projected biofuels mix. Also, the impacts of different policy options can now be analysed.

The structure of this report is as follows: In section 2, we specify the model assumptions and inputs we applied for this study. Section 3 shows the development of biofuels and their impacts at different ambition levels for biofuels. In section 4, we analyse the impacts of a number of additional policy options. Section 5 contains some additional sensitivity analyses and section 6 contains the key conclusions.

2 General assumptions

2.1 Shaping of the model

The principal objective of the Biotrans model is to find the optimal (least cost) configuration of resources and trade, for meeting a specified biofuel demand in a group of countries, given and constrained by a number of assumptions on economic and technological parameters in a specific target year. In its setup, it relates most closely to a fuel market to which a biofuels obligation is imposed, as such an obligation also stimulates meeting a target in the most (short-term) cost effective way. The model strictly aims at least-cost optimisation; therefore its starting years have not been fed with e.g. production statitics for biodiesel and bioethanol.

A comprehensive technical description of the Biotrans model and its basic assumptions can be found in Lensink et al. (2007). In the final REFUEL runs, we made some specific alterations to the model on biofuels included and on end use which we shortly describe here.

2.1.1 Biofuels included in the analysis

In general, the Refuel project is not about which biofuels will 'win' and which will 'loose', but about providing a road map with policy actions necessary to achieve certain targets. Therefore, not all biofuel chains have to be covered, and for practical reasons not all biofuel chains could be covered either. Limitations on data availability, model runtime, and interpretability of results, lead us select the following biofuel chains.

The BIOTRANS model runs for REFUEL include biodiesel, bioethanol (from sugar, starch and cellulose), Fischer-Tropsch diesel, DME and SNG (from gasification as well as anaerobic digestion). Biodiesel and bioethanol from sugar and starch crops are the biofuels currently dominating the market; bioethanol from cellulose and Fischer-Tropsch diesel are often mentioned as future biofuels. DME and SNG were added as they might add additional insights since they require new distribution and end-use infrastructure.

Pure plant oil is not included, because it has mostly been a niche fuel so far. However, since the feedstock is the same as for biodiesel and the costs are very similar, the results for biodiesel could be interpreted as applying to pure plant oil as well. The same holds for ETBE in relation to bioethanol, although ETBE has limited potential because its production from bioethanol requires isobutylene, a by-product from fossil oil refineries which cannot be produced cost-effectively on purpose. Biomethanol, currently less actively advocated than it once was, has a production process very similar to DME, although it is a petrol replacement in stead of a diesel replacement. Its potential for blending in gasoline is much more limited than that of bioethanol. HTU diesel is still under development and makes use of wet biomass waste streams for which potential and costs are difficult to estimate. Biohydrogen is expected to have potential only in combination with fuel cell-based powertrains, which are not expected to become available on a significant commercial scale before 2030.

2.1.2 Distribution and end use

The biofuels are used in three different segments of road transport: passenger cars, buses and trucks. The distribution costs of the different biofuels are assumed similar amongst these segments. Differences in distribution costs are mainly caused by the different energy contents and volatility of the different fuels, which makes distribution of DME and SNG expensive compared to the other options.

End use costs involve the costs for adapting vehicles for the use of biofuels. These are additional (or avoided) costs compared to petrol or diesel use. For biodiesel, bioethanol and Fischer-Tropsch diesel the additional end-use cost are low or even zero. The end use of DME and SNG in passenger cars appears to be expensive; the use of DME in trucks and buses is not. End use costs are difficult to estimate; therefore we kept the approach simple and did not take into account any learning and scaling effects in end use. Furthermore, we left any impacts of blends and pure fuels on other emissions (e.g. NO_x, particles) out of consideration.

2.1.3 Technological learning in Biotrans

Key feature in Biotrans is the modelling of technological learning. For 1st generation biofuels, a conventional learning approach (IEA, 2000) was adopted, based on historic analysis of progress ratios. For 2nd generation biofuels, cost reductions are mainly related to increases in scale. These scale dependent cost reductions are bounded by several constraints. Each technology has a maximum scale size, the size beyond which scale increase does not result in lower production costs. It also has a maximum doubling time, thus the scale of a production facility can only double every three to five years typically. Finally, it has a maximum market share, thus each facility can only serve a fixed fraction of the total market, typically 5-10%. Specific assumptions on these parameters per technology have been included in the data report (Deurwaarder et al., 2007).

2.2 Input data

Most input data for the Biotrans runs in REFUEL were summarised in Deurwaarder et al. (2007). Two types of specific external input data are shortly dealt with here: estimations on future gasoline and diesel demand, and the biofuels targets to be set. Cost-supply curves for the different energy crops were supplied by Wit et al. (2007), in the REFUEL WP3 report.

2.2.1 Gasoline and diesel demand

Data on future energy demand in EU27 transport up to 2030 were obtained from the 2006 PRIMES scenarios on energy demand (Mantzos and Capros, 2006). We took the energy efficiency (EE) scenario as a basis, for consistency reasons with REFUEL WP5 for which the EE scenario was a more adequate basis than the PRIMES baseline (see Berndes et al. (2007)). Note, however, that energy demand in the road transport sector, and corresponding gasoline and diesel demands, do not differ greatly between the PRIMES EE scenario and the PRIMES baseline. The same applies to the gasoline/diesel split and demand from the different end use sectors in Biotrans.

2.2.2 Shares and targets for biofuels

In terms of biofuels (target) shares, we defined three cases: a baseline, a moderate case and a high case. The target levels are summarised in Table 1.

In the *baseline*, the share of biofuels in gasoline and diesel supply equals the shares in the PRIMES EE scenario until 2030. This scenario is roughly based on implementation of current policies, without any additional efforts.

In the *moderate case*, a pathway is analysed with minimal implementation of the new ambitions in the EU Energy Package and EU 2007 Spring Council (Anonymous, 2007b). That is, it is assumed that the 2010 target of 5,75% is not met, and a 10% target for biofuels in 2020 is implemented. In a linear extrapolation, we then assume a 2030 target of 15%.

In the *high case*, we analyse a pathway in which the 2010 target is met. The 2020 target is based on what is considered an ambitious level in the Biofuels progress report (EC, 2007a) and its accompanying working document (EC, 2007b), viz. 14%. For 2030, we use a 25% target, derived from the ambition level of the Biofuels Research Advisory Council (BioFRAC, 2006).

Table 1: Biofuel target percentages in the different cases.

% biofuels	2005	2010	2015	2020	2025	2030
Baseline	1.4	4.0	5.7	7.4	8.4	9.1
Moderate case	2.0	5.0	7.5	10.0	12.5	15.0
High case	2.0	5.8	9.9	14.0	19.5	25.0

The main reason for choosing a moderate and a high case was to analyse to what extent the model responds differently between the two target pathways. As shown in section 3, the two cases follow roughly the same biofuels development pathway; in the high case, however, effects of the introduction of new fuels, and development in the average costs, are more clearly present.

For this reason, we chose to use the high case as a basis for the different policy variants in section 4. This, however, does not imply that this case should be preferred over the moderate case; it is only because the high case is somewhat clearer in showing the impacts of different policy options as well.

2.3 Assumptions for the impact assessment

In this report, two types of impacts are assessed for the different model runs: impacts on greenhouse gas emissions of gasoline and diesel use and on EU security of energy supply in transport. Impacts of the model runs in socio-economic terms have been assessed in the REFUEL WP6 report (Duer et al., in prep.).

For greenhouse gas emissions, data overviews were provided by Joanneum Research on the basis of the CONCAWE/EUCAR/JRC well-to-tank study on alternative fuels (Edwards et al., 2006) and on additional data prepared by Joanneum. The data inputs on greenhouse gas emissions in Biotrans are summarised in Annex 1. Two results are provided here for each model run: the reduction percentage of greenhouse gas emissions from gasoline and diesel use due to biofuels introduction, and the average greenhouse gas emission reduction of the introduced biofuels, as a percentage of fossil gasoline and diesel emissions.

Impacts on EU security of energy supply in the transportation sector were calculated as changes in the import dependency for liquid fuels. As the transport sector depends almost completely on oil, this is an acceptable proxy for import dependency in transport. Data on the PRIMES EE scenario (i.e. the baseline of this study) were obtained from the 2006 study for DGTREN (Mantzos and Capros, 2006). For other model runs, it was assumed that the biofuel production additional to the baseline would lead to a corresponding decrease in fossil oil imports (and not to a decrease in domestic production). Note that we neglected any differences in fossil energy inputs related to the production of biofuels and fossil fuels. Generally, production of conventional biofuels has a significantly larger fossil energy input than production of fossil fuels, while production of 2nd generation biofuels has a comparable or lower input (Edwards et al., 2006).

3 Biofuel options development in the base cases

In the 'standard' Biotrans runs with moderate or high biofuels targets, 1st generation biodiesel meets demand in the initial years. Due to the exhaustion of low-cost oil crop production potential, advanced biofuels, viz. FT-diesel, enter the market between 2010 and 2014, depending on the ambition level of the target pathway. In following years, this biofuel meets most of the increase in biofuel demand; by 2030, FT-diesel has market share between one- and two-third, with biodiesel supplying the remaining share. In these standard cases, FT-diesel is the 2nd generation biofuel with the highest probability of introduction, but there is also a considerable chance that 2nd generation bioethanol will be the dominant advanced biofuel.

Initial feedstocks for FT-diesel are wood processing residues and agricultural residues, and in the high case the first woody crops enter the feedstock supply mix substantially only after 2020. Production of oil crops for biodiesel starts in CEE countries, and this remains the dominant crop there. In later years, when cultivated 2nd generation biofuel feedstocks enter the market, this supply is strongly dominated by woody crops from France and the Eastern part of Ukraine.

The exhaustion of low-cost potential for biodiesel is accompanied by a moderate increase in average biofuel costs, inducing the entrance of FT-diesel. Both biofuels become cheaper on average over the years, but as the share of (more expensive) FT-diesel increases, the average biofuels costs remain relatively stable over the years.

As the target share for biofuels increases, their induced greenhouse gas emission reduction increases more than proportionally. This is because FT-diesel, with its superior greenhouse gas performance compared to biodiesel, has a larger share of supply with increasing ambition levels. Biofuels also lead to an increasing share of domestic fuel supply in transport.

In this chapter, we present the model outcomes for the two cases with high and moderate biofuel targets, and compare them to the baseline developments. In the discussion of the outcomes, we pay more attention to the high case than to the moderate case. This is because in the high case, many effects are more clearly present in the model outcomes; it does not signify any preference for this case.

For this analysis, we made the following assumptions;

- No ex-EU imports of biofuels or feedstock;
- No subtargets for specific biofuel types, such as 2nd generation biofuels, or specific minimum shares for gasoline and diesel substitutes;
- The biofuels consumption targets are applied to each individual EU member state;
- No pricing of CO_2 emissions;
- No additional policies (such as investment subsidies or crop support).

First, we go into the developments in the biofuels mix in the baseline, then the moderate and high cases. Finally, we present the impacts of the three runs in terms of overall costs, avoided greenhouse gas emissions and energy security.

3.1 The baseline

As Figure 1 shows, the biofuels mix in the baseline remains dominated by biodiesel. The feedstock potential in terms of low-cost oil crop production areas and residual fats and oils is sufficient to meet the expected 9% share of biofuels by 2030. The average costs per GJ biofuel over time hardly increases until 2030: in the first years, crop costs increases as the relative share of crops in the feedstock mix increases at the expense of the used fats/oil share, but this is largely compensated by reductions in conversion costs in the same period.

In the baseline, and in all other cases of this chapter, ethanol does not enter the market. This is mainly due to higher costs of this biofuel compared with biodiesel, and in a later stage, with FT-diesel. In these cases, the model does not specify targets for the gasoline and diesel sectors; such variants are included in Chapter 4. Note, however, that

3.2 The moderate case

When applying the moderate biofuels targets of the moderate case to the model, 2nd generation FT-diesel is competitive to a small part of the additional biodiesel supply by 2014, and therefore introduced in the mix. In that year, biodiesel production reaches ca 900 PJ (or 21 Mtoe), or 7% of the total gasoline and diesel demand by then. The introduction of FT-diesel occurs mainly because the higher biofuel target by then leads to full exploitation of oil crop production areas in the lower part of the corresponding cost-supply curve, and oil crops start being cultivated on additional lands where the production costs per GJ feedstock are higher (either because of lower yields or because of higher management costs). By 2012, the marginal costs of biodiesel reach the level of the cheapest options for FT-diesel, and FT-diesel enters the market. By 2030, biodiesel still has roughly two-thirds of the market, with FT-diesel having the other one-third.

For the production of FT-diesel, wood processing residues are first applied as a feedstock. Within a couple of years, agricultural residues start being used as well. In the moderate case, these resources are almost fully sufficient supply to FT-diesel production: there is hardly any use of cultivated woody or grassy crops. Note that forestry residues are not applied either, because of their higher costs. In the moderate case, FT-diesel production remains dominantly based on residues from wood processing and agriculture until 2030.

3.3 The high case

In the high biofuels target case, the essentials of the developments are identical to those in the moderate case, but all effects are more pronouncedly visible in the figures and graphs. For example, FT-diesel is introduced at a more rapid pace after 2010. Due to the higher biofuels target, low-cost biodiesel options run out of potential earlier as additional oil crop cultivation becomes more expensive. In later years, almost all additional biofuel production is covered by FT-diesel. By 2030, it covers ca two-thirds of the market, with biodiesel having one-third.

As in the moderate case, initial FT-diesel production uses wood processing and agricultural residues. However, the higher targets force a substantial amount of woody crops into the feedstock mix from 2020 and beyond. While in the moderate case, residues are the only significant feedstock base for FT-diesel, in the high case their share is slightly under 50%.

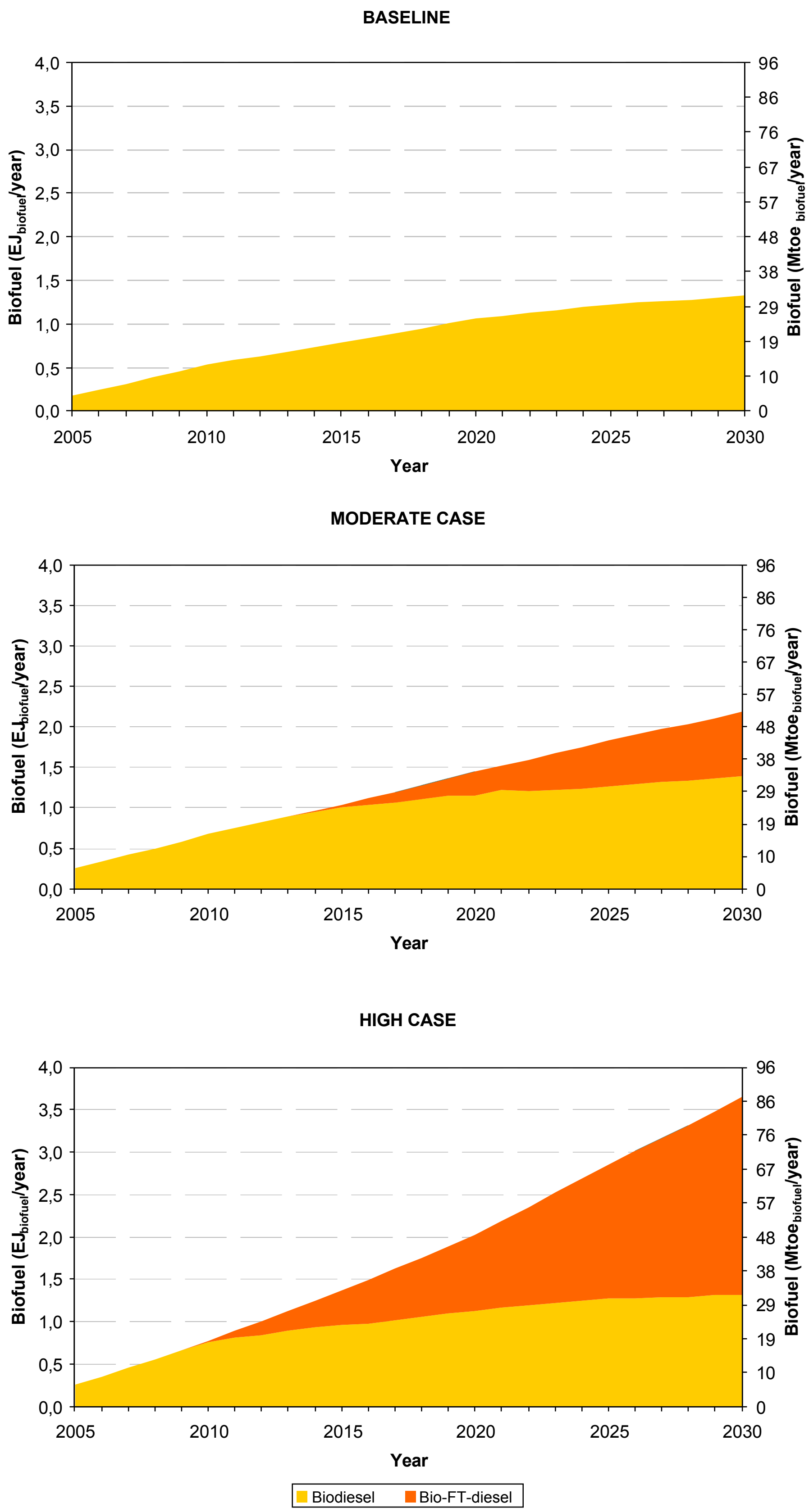

Figure 1: Biofuels shares in the baseline, moderate and high cases.

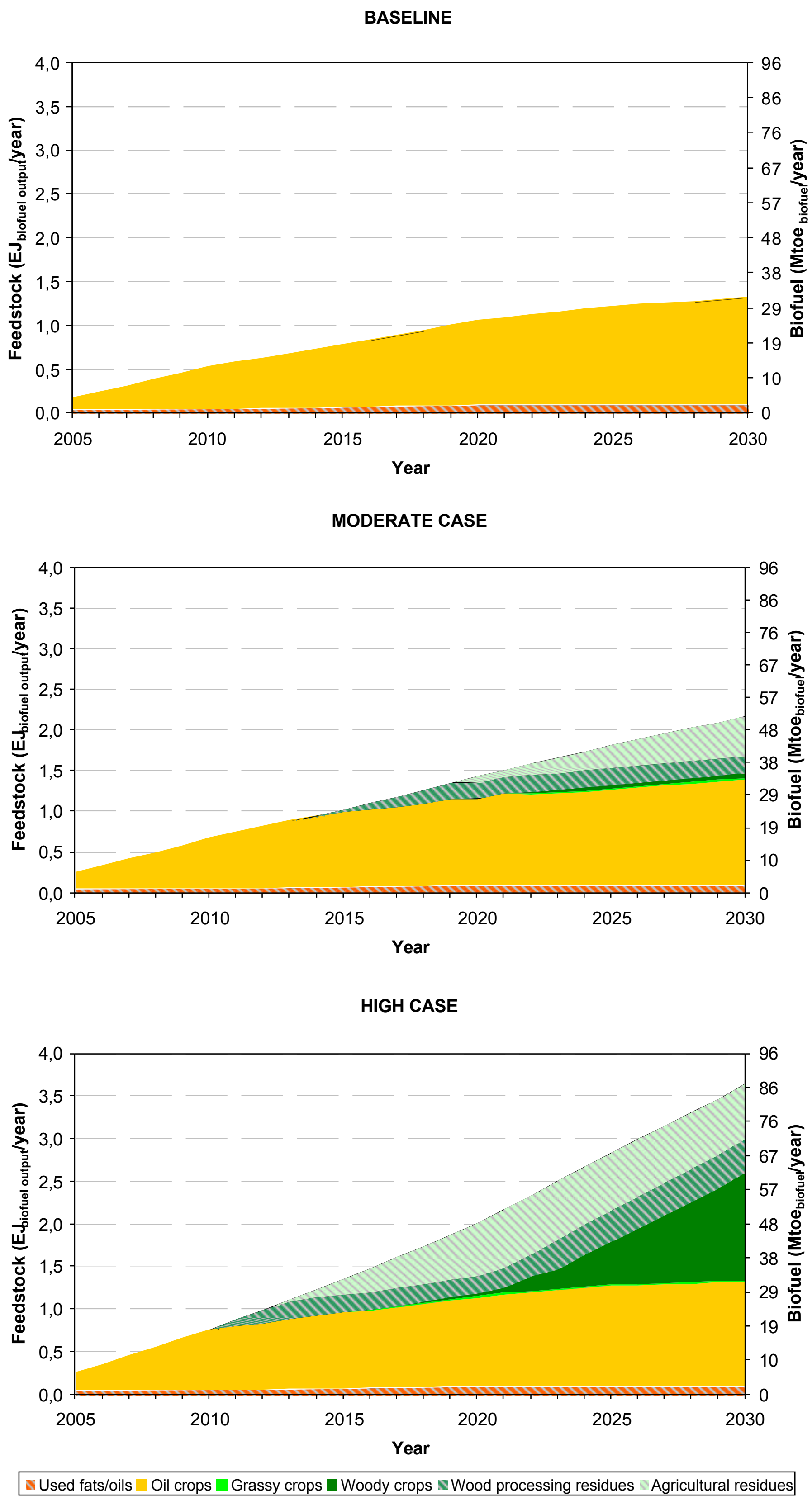

Figure 2: Feedstock supply in the baseline, moderate and high cases.

3.4 Biofuel costs

In the average biofuels costs, the introduction of FT-diesel first occurs at increasing overall biofuels costs. As can be seen in Figure 3, feedstock costs first increase, as biodiesel production starts using feedstock produced at higher costs. When FT-diesel is introduced in 2010, average feedstock costs decline due to the low-cost residues for this fuel, but initial conversion costs are high, leading to an overall increase in biofuel costs for one additional year. Between 2014 and ca 2030, average biofuel costs remain roughly the same: both biodiesel and FT-diesel become cheaper, but as the share of more expensive FT-diesel increases, the overall costs stabilise.

For FT-diesel, cost reductions due to technological learning can be clearly observed in the development of average FT-diesel fuel costs over time. From 2010 onwards, processing costs decrease substantially as installation scale increases. On the other hand, as the target level increases, larger parts of the feedstock cost-supply curve are used, leading to slightly increasing feedstock costs that dampen the cost reduction effect of learning in processing.

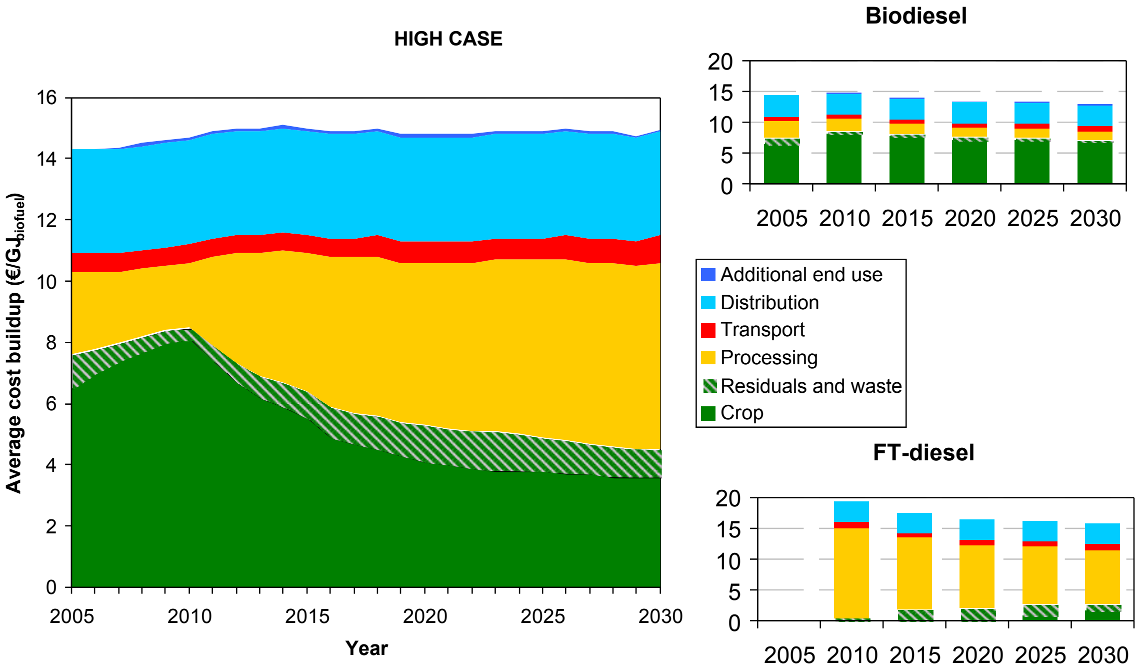

Figure 3: Average biofuel costs over time for the high case.

As can be seen in Figure 4, the aggregated costs for biofuels (in €/GJ fuel) increase from the baseline to the moderate case to the high case. This because with increasing targets, more expensive parts of the overall cost-supply curve enter into production. However, this cost increase is relatively minor: the difference in average costs per GJ fuel between the high case and the baseline increases over time as the target levels diverge, but by 2030 the difference is still only 12%. Note, however, that the total costs of biofuels do increase proportionally with increasing targets, leading to significant differences both over time within each case and between the cases.

The average biofuel costs remain relatively stable over time. Even in the high case, which has the clearest cost peak around 2010, the difference between the highest costs and the lowest between 2005 and 2030 is less than 5%.

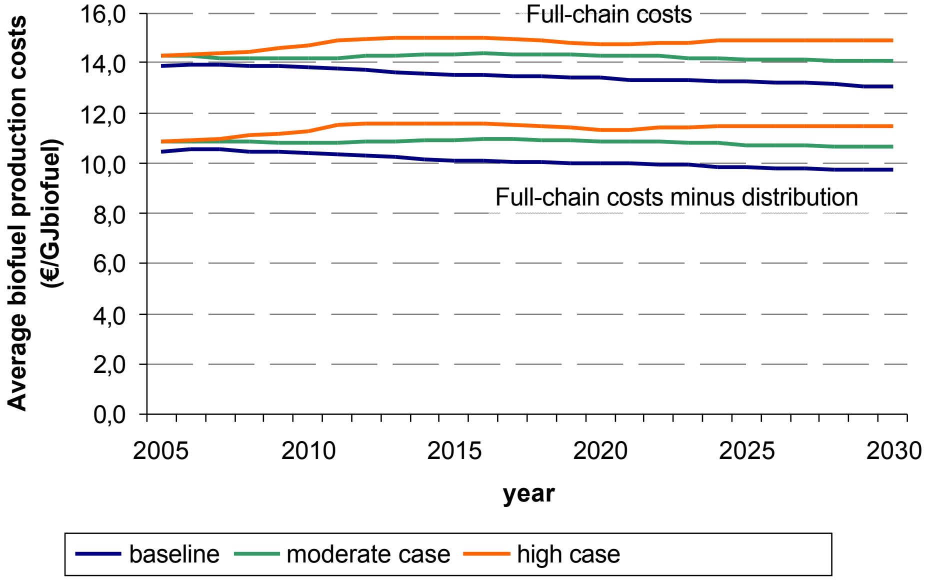

Figure 4: Aggregated costs for the baseline, moderate and high cases.

3.5 Key feedstock producing regions

Figure 5 shows the geographical distribution of feedstock production areas and the dominant crop(s) per region for the high case. In the early years, when the fuel mix only consists of biodiesel, an increasing share of land is used for oil crops. Initially, only regions in Central and Eastern European countries and Ukraine start producing, but by 2010 also parts of Western European have started production. After 2010, when FT-diesel enters the market, new feedstock mainly consist of woody residues, that are not shown in the land use graphs of Figure 5. But by 2020, the first regions have started producing woody crops, mainly in the regions around the Mediterranean. Between 2020 and 2030, most additional feedstock consists of wood crops, and large parts of France, the east part of Ukraine, Italy and Spain produce woody crops. Quite strikingly, oil crops remain the dominant biofuel feedstock in the Central and Eastern European countries. This is probably because the cost difference between woody crops and oil crops is smaller in these countries than in Western European countries (e.g. due to higher costs for labour and for land in the latter countries, leading to lower costs for less labour-intensive cultivations such as wood y crops).

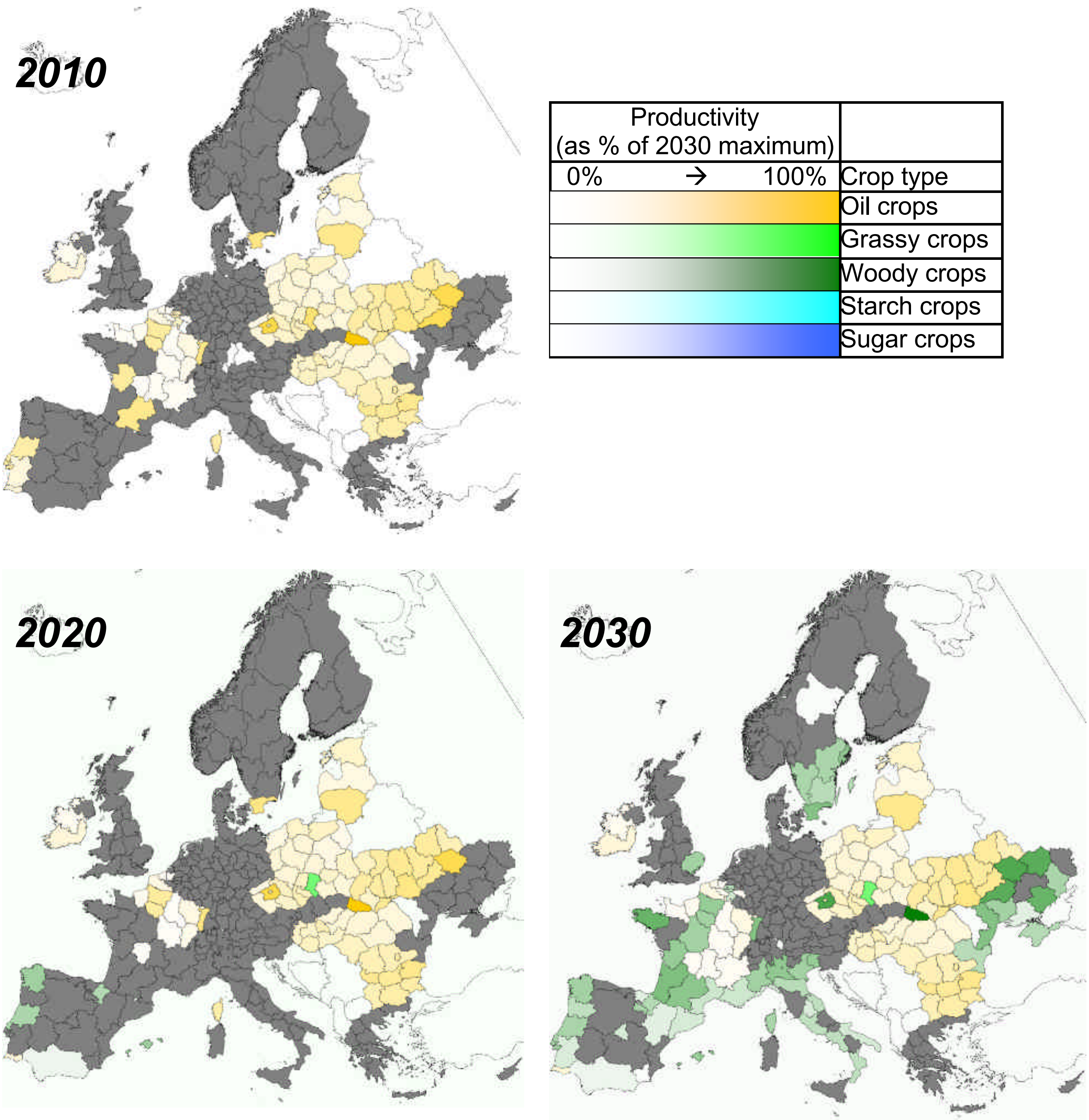

Figure 5: Feedstock producing regions, their dominant crop(s) and relative productivities in the high case.

3.6 The probability of 2nd generation biofuels break-through

One of the eye-catching outcomes in the moderate and high cases is the entrance of only one 2nd generation biofuel. Since Biotrans is a least-cost model in which a newly introduced 2nd generation biofuel starts learning and reducing processing costs, this effect could be expected: once a specific 2nd generation biofuel enters the market, the odds for a competing option to enter as well declines rapidly. However, the Monte Carlo sensitivity analysis gives an impression of the probabilities for the different 2nd generation options to penetrate. Further details on this analysis are given in chapter

5, but in Figure 6, these probabilities are given for the high case. Within the ranges used for the MC analysis, the chance that FT-diesel enters the market is ca 65%. But in addition, there is a 25% probability that 2nd generation ethanol enters. Finally, there is a 15% chance for DME to enter, of which 10% as the only 2nd generation biofuel, and 5% in combination with FT-diesel. This illustrated that FT-diesel is not the clear-cut overall winner of all advanced biofuel options, although it does have the best relative prospects.

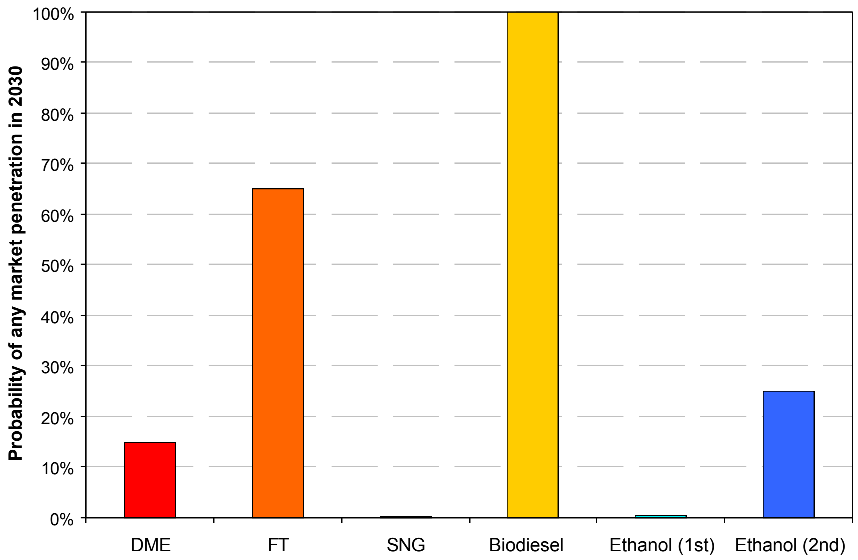

Figure 6: Probabilities of market entrance for the different biofuels in the high case.

3.7 Greenhouse gas impacts

Table 2 shows the greenhouse gas emission reductions that can be attributed to the presence of biofuels for the three cases in 2030. As the baseline contains a 9.1% share of biofuels by then, the baseline emission reduction is not zero. Two key effects can be observed:

- As the target shares of biofuels increase, the greenhouse gas emission logically increases;
- As the high case induces a larger share of 2nd generation biofuels, with low greenhouse gas emission compared to fossil fuels, the reduction increases more than proportionally with the target level.

Table 2: Greenhouse gas emission reductions in the three base cases in 2030.

Target pathway	Reduction percentage of greenhouse gas emissions from gasoline/diesel use	Average greenhouse gas emission reduction of the applied biofuels mix
Baseline	5,4%	59%
Moderate case	10,9%	73%
High case	20,4%	81%

3.8 Impacts on security of energy supply

In Table 3 the impacts of the three cases on EU import dependency of liquid fuels are summarised. As can be expected, enhanced introduction of biofuels leads to a significant decrease in import dependency, by almost the same percentage as the target percentage for biofuels. The difference occurs since the biofuels target is calculated as a share of gasoline and diesel use, while the import dependency figures also take into account the use of kerosene in aviation. However, since kerosene demand does not increase dramatically in the PRIMES EE scenario, the difference remains rather small.

Table 3: Import dependency for liquid fuels 2010-2030 for the base cases.

Import	2010	2020	2030
Baseline (PRIMES EE scenario)	83,4%	92,2%	93,1%
Moderate case	82,5%	89,4%	86,7%
High case	81,9%	85,8%	77,6%

4 Analysis and evaluation of additional policy options

Next to the biofuels target, several additional policy options were analysed, with the high case as a basis. Adding imports to the biofuel mix leads to a later introduction year of 2nd generation FT-diesel, either to be considered as a delay or as 'buying some more time' for technological development related to advanced biofuel production. It reduces and stabilises the overall (direct) costs of biofuels due to the introduction of low-cost feedstock. Logically, the introduction of a CO_2 emission pricing mechanism leads to some shift towards more 2nd generation biofuels with a 20% increase of the FT-diesel share; impacts on net biofuel costs are negligible. Investment subsidies on biofuel production plants induce a ca 10% shift towards 2nd generation biofuels, again at very limited cost. On the contrary, an energy crop premium leads to a significantly higher share of conventional biodiesel, at significantly higher costs. A specific target for gasoline and diesel markets does leads to strong changes in the biofuels mix: in the initial years, 1st generation ethanol is forced into the market; after 2010, the 2nd generation ethanol is the first advanced biofuel entering the market, followed by FT-diesel around 2025. This policy induces increased average costs. An active policy on other biomass applications leads to the introduction of more land-efficient biofuel chains, at additional costs. By 2030, advanced FT-diesel almost entirely dominates the biofuels mix, against additional costs of circa 10%. The impact in terms of GHG emissions differs quite between these four policy options. In general, cases with a higher share of 2nd generation biofuels have better GHG emission reductions against limited additional costs. The case with subtargets for gasoline and diesel has a relatively poor ratio between GHG performance and costs, while the biofuels responding to feedstock scarcity in the case with high RES-E/H ambitions have the best GHG emission profile at limited cost increase.

Some policy measures hardly influence the biofuels and feedstock mix, but do affect costs. Burden sharing, i.e. setting an overall 25% EU target in stead of targets per country, leads to significant shifts of biofuel consumption. Countries with large potentials of low-cost feedstock (e.g. Bulgaria, Romania and Poland) experience biofuel shares over 50% while countries with limited low-cost feedstocks, such as Denmark, the Netherlands and Germany, reach shares of under 5%. Average biofuel costs are reduced by ca 0.3 €/GJ.

The results in section 3 give an indication for the development of biofuels in a context in which only one a target share is applied to increase the amount of biofuels as cost-effectively as possible. In this section, we analyse the impacts of additional policy measures, and show their influence on the biofuels and feedstock mix, overall costs, greenhouse gas emission reductions and import dependency. Analysed policy options that affect the development of the biofuels mix were:

- The situation in which imports also contribute to biofuels target (4.1);
- Introduction of CO_2 pricing policy (4.2);
- The introduction of investment subsidies for biofuel production (conversion, 4.3)
- The introduction of an energy crop premium (4.4)
- The introduction of specific subtarget for gasoline and diesel substitutes (4.5);
- The introduction of ambitious policies for biomass in E and H, leading to reduced feedstock availability for biofuels (4.6).

Section 4.7 shows the greenhouse gas impacts of the biofuels mixes as induced by the different policy measures.

Furthermore, two policy options that only affect EU-domestic trade were analysed:

- Impact of an overall EU target versus a specific target per EU member state (4.8);
- Transport of feedstock versus transport of fuel (4.9).

Finally, we analysed the impact of a specific subtarget for 2^{nd} generation biofuels. However, as this type of biofuels already enters the mix in the 'standard' high case, such a target does not affect the development of the mix, unless subtargets above 70% by 2030 are applied. Therefore, this policy measure is not further analysed here, although it may serve as a back-up option to ensure the introduction of 2^{nd} generation biofuels in variants in which they do not enter the mix autonomously.

4.1 The effect of imports

In the standard cases of section 3, biofuels targets are completely met by domestic supply. In order to see the impact of imports, we did a model analysis with imports possibilities of bioethanol from Latin-America and palm oil from South-East Asia. For data on import potentials and costs see Deurwaarder et al. (2007), we also included an upper limit of 30% for imports in the total biofuels mix. Note that we did not take any market barriers into account for palm oil use in biodiesel, such as the current iodine number limit in the EN14214 biodiesel standard.

Figure 7 and Figure 8 show respectively the biofuels mix and the feedstock mix for this policy variant. Palm oil imports enter the mix from the starting year on, and are finally applied up to their maximum potential. By 2015, imported bioethanol starts to enter the biofuels mix because palm oil imports and domestic oil crop supply runs out of additional potential. Ethanol imports grow substantially in the following years. By 2019, FT-diesel enters the market, and rapidly increases its share in the mix, partly at the expense of ethanol imports. By 2030, FT-diesel has an almost 50% share of the mix, biodiesel has also 50%, and bioethanol has gone down to 3%.

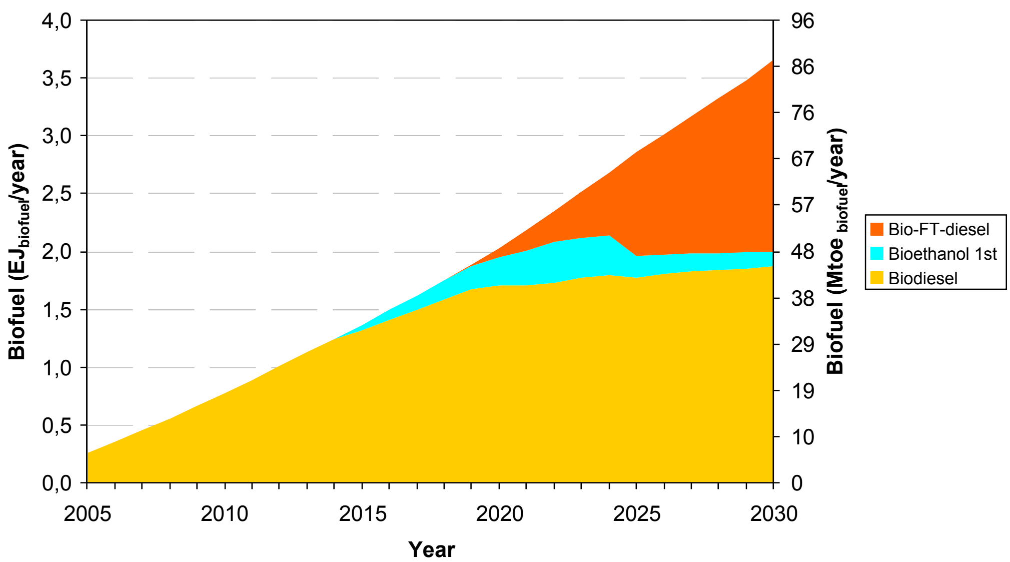

Figure 7: Biofuels mix in the policy variant with imports allowed.

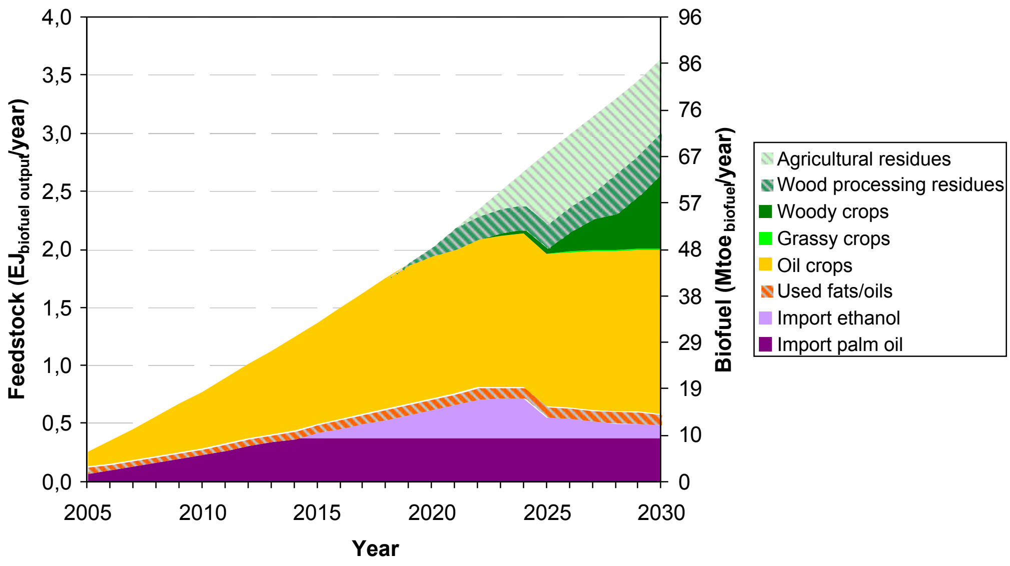

Figure 8: Feedstock mix in the policy variant with imports allowed.

In the development of the aggregated cost build-up (Figure 9), the impact of imports can also be clearly observed. Overall, the average biofuel costs are lower over the entire chain (cost differenc shown in the figure as the ‘difference with high case’ item), due to the availability of more low-cost feedstock. Particularly in the period until 2020, biofuel imports lead to significantly lower average costs, up to 2 €/GJ. However, FT-diesel is introduced relatively late, and by 2030 this option has not gone down the learning curve as far as it does in the standard high case, leading to relatively high costs. These two effects roughly balance each other out in the period between 2025 and 2030: there is hardly any cost difference between the import case and the standard high case. On one hand, one can conclude that imports delay the introduction year of advanced biofuels. On the other hand, one can argue that imports are an effective option to buy some additional time for the development and commercial introduction of these technologies.

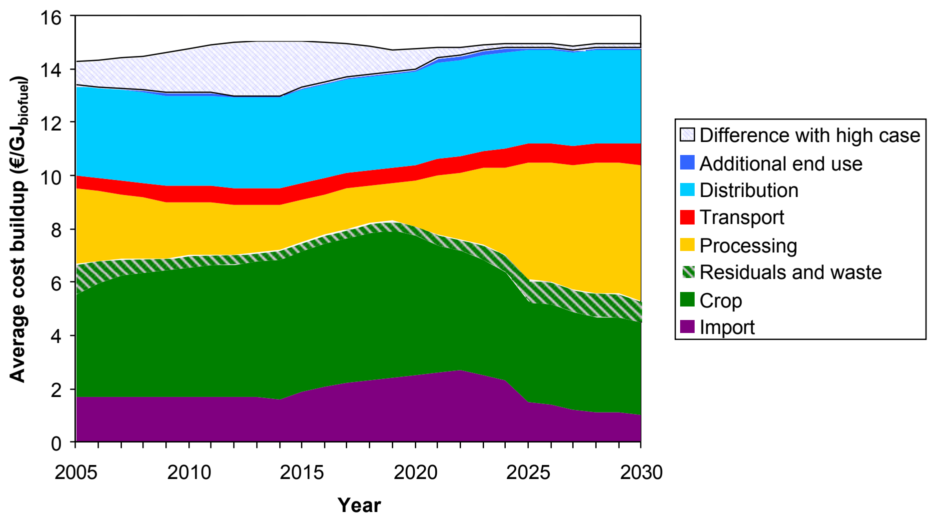

Figure 9: Aggregated biofuel cost build-up in the policy variant with imports allowed.

In short, adding imports to the mix has the following impacts:

- It leads to a somewhat later introduction year of 2nd generation FT-diesel. This might be considered a negative impact; but it can also be seen as 'buying some more time' for technological development related to FT-diesel production.
- It reduces the overall (direct) costs of biofuels due to the introduction of low-cost feedstock.
- It delays and decreases the cost hurdle related to the exhaustion of low-cost domestic oil crop potential and leads to a more stable development of average costs.

4.2 Introducing a CO_2 price in the transportation sector

Apart from the oil refinery sector, the transportation sector is currently not part of the EU-ETS, and therefore climate policy does not affect biofuels. However, it is quite conceivable that either transport will enter the ETS system, for example, in the post-2012 period, or that the greenhouse gas emissions of fuels will be priced otherwise. This will also allow rewarding the differences in greenhouse gas performance of different biofuels.

Therefore, we also analysed what happens to the biofuels mix in Biotrans when a CO_2 taxation is introduced. Here, we started with a CO_2 price of 20 €/tonne CO_2-eq, increasing this linearly to 70 €/tonne CO_2 by 2030. Figure 10 shows the changes in the biofuels mix induced by this CO_2 pricing. While in the standard high case, biodiesel remains almost constant after 2010, this biofuel with its relatively poor CO_2 profile is now gradually decreasing in its absolute contribution at the benefit of an increased volume of FT-diesel, which has a far better greenhouse gas performance. By 2030, almost one-third of the original volume of biodiesel in the high case is replaced by FT-diesel in the CO_2 pricing case; FT-diesel now has 75% of supply.

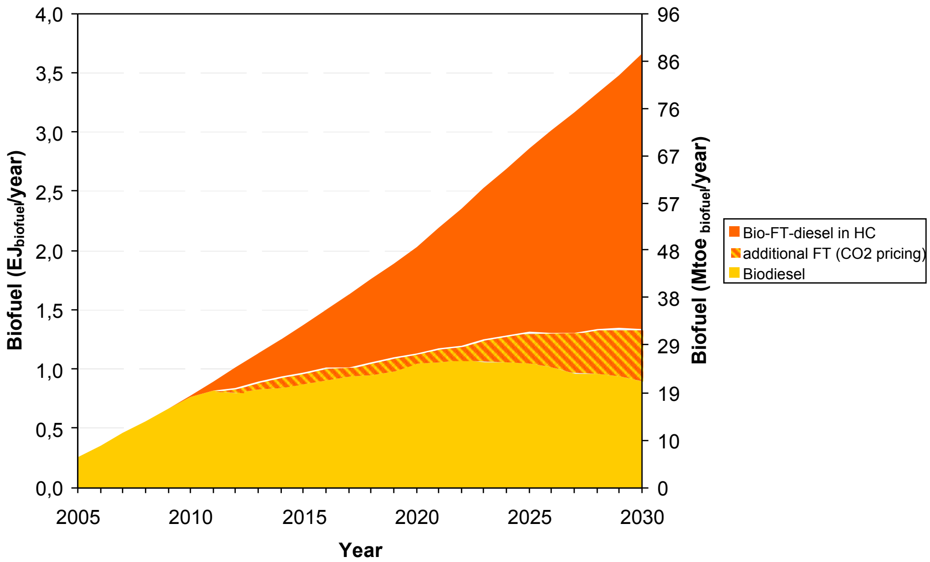

Figure 10: Biofuels in the policy variant with CO_2 pricing.

The average costs of biofuels are affected by this policy in two ways: first, biofuels costs increase due to the pricing of greenhouse gas emissions. Second, the greenhouse gas pricing induces a change towards a more expensive, but greener biofuel mix that has higher production costs than the original mix in the high case. By 2030, the CO_2 pricing pathway leads to an increase in the average costs of biofuels of 1 €/GJ. This cost increase consists almost completely of the costs of CO_2 itself; as these costs can be considered income for the tax receiver, these cost should be left out of the comparison with other variants. The additional costs for the more climate-neutral biofuels themselves is only 0.1 or 0.2 €/GJ. As in the variant with an investment subsidy, this is mainly because

In short, CO_2 pricing leads to some shift towards a larger share of 2nd generation biofuels. Impacts on net biofuel costs are negligible, but the costs of CO_2 emissions add ca 1 €/GJ to the biofuel costs.

4.3 Introducing an investment subsidy on conversion

An often-mentioned (and regularly applied) instrument for enhancement of biofuels is the introduction of investment subsidies for conversion installations. Therefore, we analysed the impact of a significant investment subsidy, viz. 50% of investment (CAPEX) costs.

As Figure 11 shows, an investment subsidy has an enhancing effect on FT-diesel in the mix. By 2030, it has a 10% larger production level than in the standard high case. The main reason for this effect is that the share of investment costs in the total cost per GJ biofuel is higher for advanced biofuels than for biodiesel, for which feedstock is the dominant cost factor.

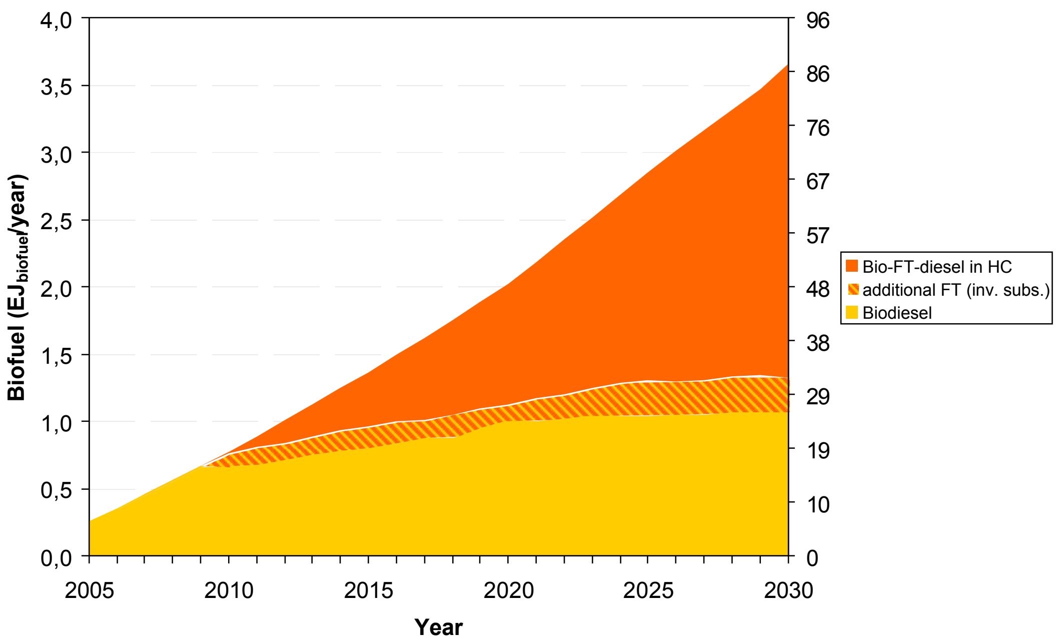

Figure 11: Biofuels in the policy variant with investment subsidies.

The average costs in this case, including the costs of the subsidy, are almost fully comparable with the costs in the standard case. Obviously, this only applies if the producers fully translate the investment subsidy into a reduction of biofuel production costs. Apparently, the subsidy induces a shift towards 2nd generation technologies, and their increased learning rate (and limited increased feedstock costs at higher demand) hardly leads to a cost increase compared to the standard case.

In short, in investment subsidy enhances FT-diesel introduction by reducing the capital costs barrier, and generally leads to some shift towards a larger share of 2nd generation biofuels. Impacts on net biofuel costs are relatively negligible.

4.4 Introducing a subsidy on energy crops

Another instrument that can be applied to biofuels is a premium on dedicated energy crops for biofuels. The current energy crop support scheme of € 45/ha/yr is an example of such a mechanism. Especially with the (significantly higher) support payments that the EU CAP knows for crops such as wheat, we analysed a case in which energy cropping farmers receive a support payment of € 200 /ha/yr. This is only a very coarse approximation of current practice for food crops in the CAP, in which support payments are differentiated between crops, and also depend on average crop productivity of the specific region. However, it is a first indication of the possible impacts.

As Figure 12 shows, an undifferentiated energy crop premium has a strong impact on the balance between biodiesel and FT-diesel. The introduction year of FT-diesel is delayed, and by 2030, the production of biodiesel is almost 50% higher than in the standard high case. This is mainly because a crop premium per ha has a stronger cost reducing impact on oil crops, with their low production per ha, than on lignocellulosic energy crops.

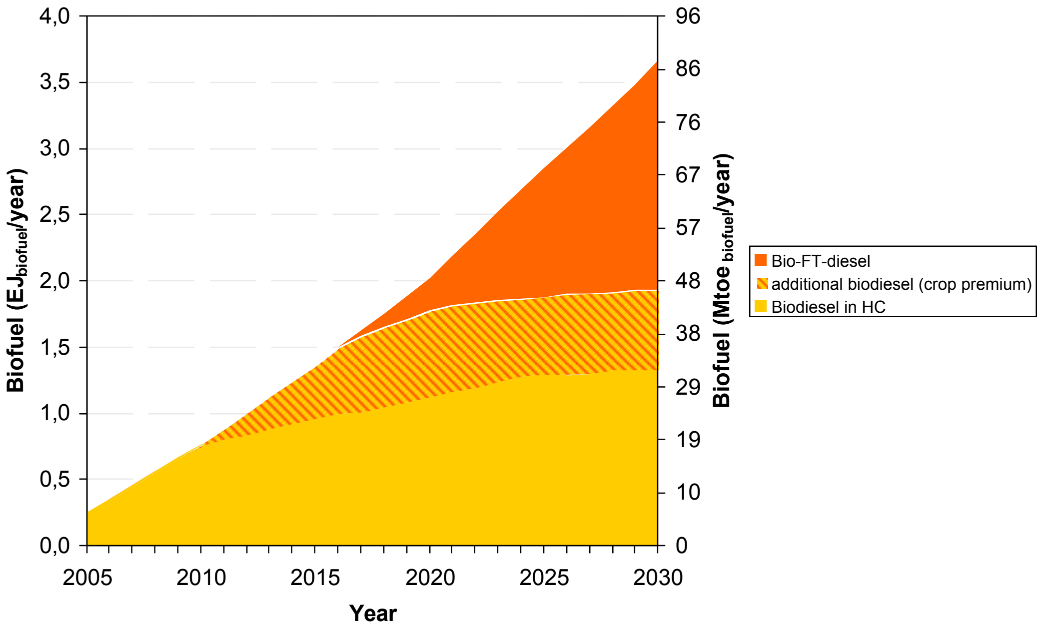

Figure 12: Biofuels in the policy variant with an energy crop support scheme.

Overall costs for biofuels (including the costs for the support scheme) are between 0.5 and 1 €/GJ higher than in the standard high case. This is mainly because the subsidy induces application of a larger part of the cost-supply curve of biodiesel feedstock. In contrast to the investment subsidy, this cost increase is not compensated by increased learning effects or other counterbalancing mechanisms.

In short, an energy crop premium as analysed in this variant is a clear supportive mechanism for biodiesel, with its relatively high-cost feedstock. The overall biofuel costs increase considerably.

4.5 Introducing specific targets for gasoline and diesel markets

Although currently not in the biofuels directive, it has often been argued that the development of biofuels would be more robust if biofuels targets would also apply to both the gasoline and diesel markets. Several countries, such as the Netherlands, have also specified this in their policy towards 2010 (Geel, 2006). Therefore, we also evaluated a model run in which the biofuel target applies both to the gasoline and diesel markets. Practically, this means that in the high case by 2030, 25% of all gasoline should be biobased, and 25% of all diesel fuel as well. For the future developments in the gasoline/diesel split of fuel demand, we used the projections of the PRIMES EE scenario.

Developments in the biofuel and the feedstock mixes are given in Figure 13 and Figure 14, respectively. In the initial years, conventional biofuels meet the demand, both for gasoline and diesel substitutes. After 2012, 2nd generation bioethanol enters the mix and fully replaces conventional bioethanol within ca five years. In the diesel market, conventional biodiesel remains the only biofuel until 2024, when FT-diesel enters the mix as well. By 2030, 2nd generation bioethanol is the only gasoline substitute, representing 25% of total biofuel production; FT-diesel has 40% of the market for diesel substitutes, representing 30% of total biofuel production; biodiesel has the remaining 60% of the diesel substitute market and 45% of all biofuels.

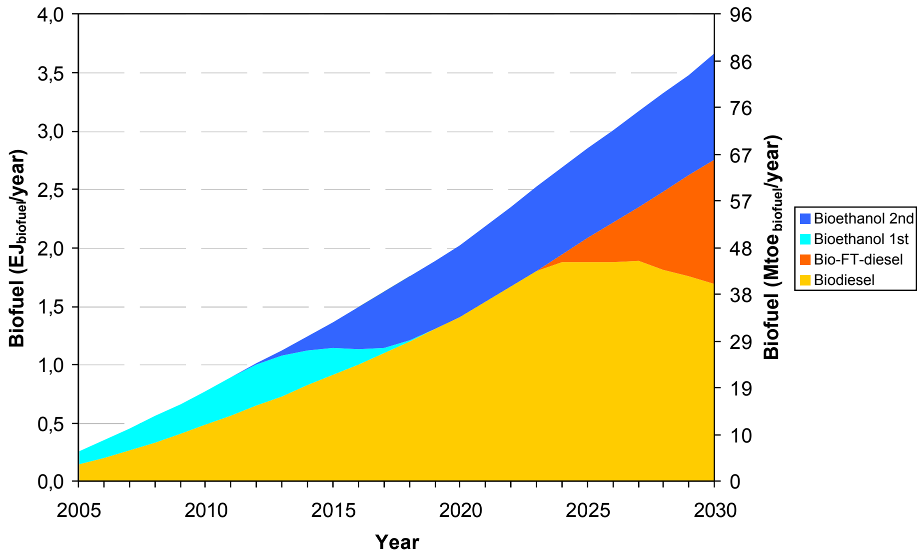

Figure 13: Biofuels in the policy variant with specific targets for gasoline and diesel.

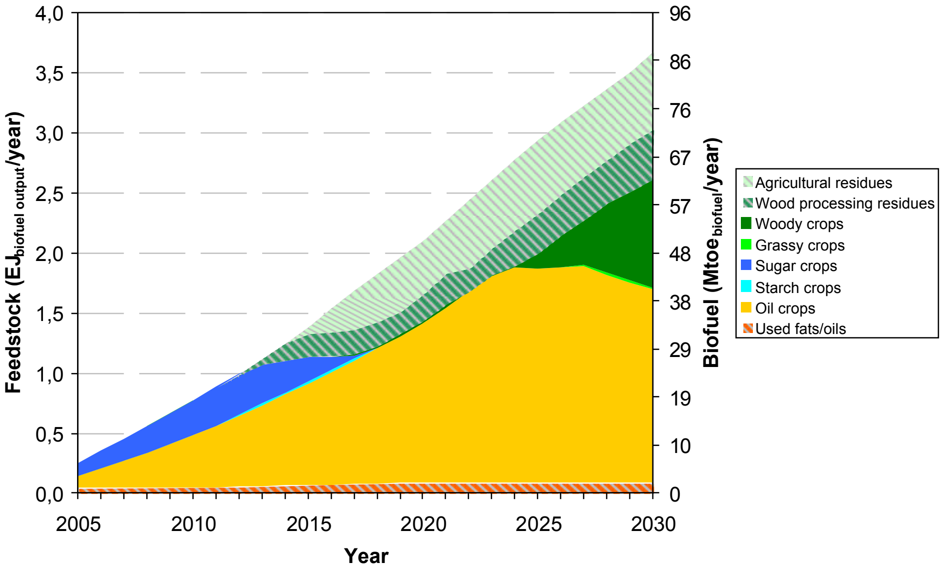

Figure 14: Feedstock in the policy variant with specific targets for gasoline and diesel.

Most clear effect of the specific target setting for gasoline and diesel is that the biofuel mix is more diverse. Furthermore, the first advanced biofuel to enter the mix is not 2nd generation ethanol. This is mainly because the cost difference between 1st and 2nd generation ethanol is smaller than the cost gap between biodiesel and FT-diesel. After its introduction, 2nd Generation ethanol rapidly outcompetes conventional ethanol, and takes up the lion's share of low-cost lignocellulosic feedstock in the process. This shift in bioethanol production from conventional crops to residues leads to an increased amount of low-cost production potential available for biodiesel feedstock. Therefore, the introduction year for FT-diesel is significantly later than in the standard high case. Only around 2025, when biodiesel eventually runs out of its low-cost feedstock, FT-diesel enters the mix. At the same time lignocellulosic energy crops are starting to be applied.

In the aggregated cost build-up (Figure 15), the obligatory ethanol share first leads to relatively high costs. After the introduction of 2nd generation ethanol, two mechanisms compensate for each other's effects: 2nd generation ethanol learns rapidly and leads to lower costs, but on the other hand biodiesel gradually becomes more expensive. Around 2024, the introduction year of FT-diesel, overall costs rise slightly because the latter mechanism dominates the former, and in the years shortly before 2030, costs slightly decrease again due to learning, now both in 2nd generation ethanol and in FT-diesel. Although aggregated costs decline over time, they are consistently higher than in the high scenario without the specification for gasoline and diesel markets. Initially, this cost difference is ca 3 €/GJ; until 20108, it decreases to ca 1 €/GJ and remains at this level up to 2030.

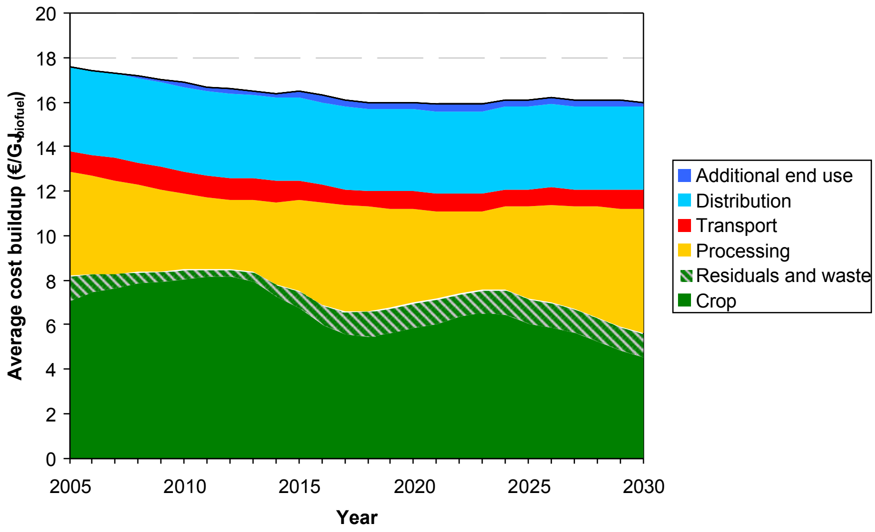

Figure 15: Aggregated cost build-up in the policy variant with gasoline/diesel targets.

As in this policy case the biofuel mix is significantly different, the probabilities for the different fuels to enter the market also change significantly. The Monte Carlo sensitivity analysis gives an impression of these probabilities; Figure 16 shows them for the high case the specific targets for gasoline and diesel substitutes. Although both FT-diesel and 2nd generation ethanol enter the mix in this variant, their introduction probabilities are in the same order of magnitude, viz. around 25%. Especially for FT-diesel, this probability is significantly lower than in the standard case. In general, while the standard high case had an almost 100% chance that either one or two 2nd generation biofuels would enter (see Figure 6 for comparison), there now is a probability of circa one third that the market will remain dependent on 1st generation ethanol and biodiesel. Key lesson of the sensitivity analysis is that splitting the biofuels market into submarkets for gasoline and diesel substitutes may lead to the development of specific 2nd generation fuels for these two markets, but also increases the probability that no 2nd generation biofuel enters the market at all.

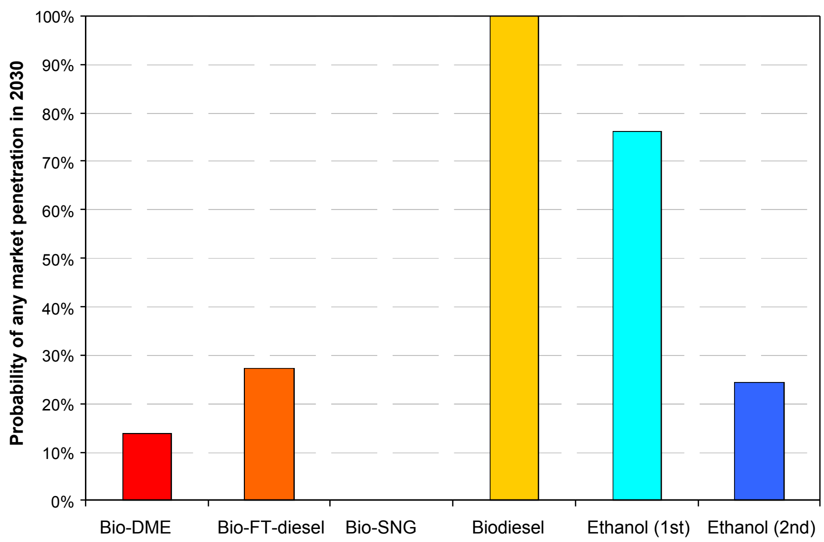

Figure 16: Probabilities of market entrance for the different 2nd generation biofuels in the moderate case with subtargets for gasoline and diesel substitutes.

In short, a specific subtarget for gasoline and diesel substitutes leads to two different submarkets, with the following impacts:

- In the initial years, 1st generation ethanol is forced into the market; after 2010, first 2nd generation ethanol substitutes the 1st generation, and the introduction of FT-diesel is significantly delayed.
- It increases the average cost of biofuels, quite strongly in the initial years, but also structurally.
- It increases the probability that no 2nd generation biofuels enter the market at all.

4.6 Introducing significant biomass demand for RES-E/H

Biofuels are not the only application of biomass feedstock. From the stationary sector, a significant demand of biomass may be expected for power and heat generation, and there may be additional demand from the material applications. Therefore, we analysed the development of biofuels in a situation where active policies on renewables in other sectors lead to only 40% of the original feedstock base being available for biofuels. In this analysis, the total cost-supply curve (expressing available feedstock (in GJ) per cost category) was reduced by 60%, assuming that both low-cost and high-cost supplies are distributed over the different application. This reduction was applied to the energy crop potentials as well as the potentials of residues.

Reduction of feedstock potential by 60% leads to the initial introduction of conventional bioethanol in the initial years, next to biodiesel. This is mainly because oil seed production is relatively land-intensive, and crops as wheat and sugar beet have a higher biofuel production per ha. After 2010, when 2nd generation technologies are introduced, both conventional ethanol and biodiesel are almost entirely displaced by 2nd generation biofuels, in this case FT-diesel. This again is caused by their limited productivity in terms of GJ biofuels per ha of land compared to more advanced biofuels. Conventional bioethanol is phased out rapidly, and biodiesel follows in later years; by 2030, FT-diesel is by far the dominant biofuel. Figure 17 shows the development in the biofuels mix. As Figure 18 shows, the feedstock base is very broad and diverse in the situation with strong limitations on feedstock availability. Basically all categories of crops and residues are applied in order to meet the targets cost-effectively. Note that it is still possible, even with a 60% reduction of the feedstock base, to meet the high biofuels demands as specified in the high case. The scarcity of biomass also has major implications for crop production and related producing regions, as shown in Figure 19. Initially, oil crops are located mainly in Bulgaria/Romania, and in some Mediterranean and Scandinavian regions, while sugar and starch crops dominate the remaining EU. Later, wood crops dominate the entire EU27 and Ukraine.

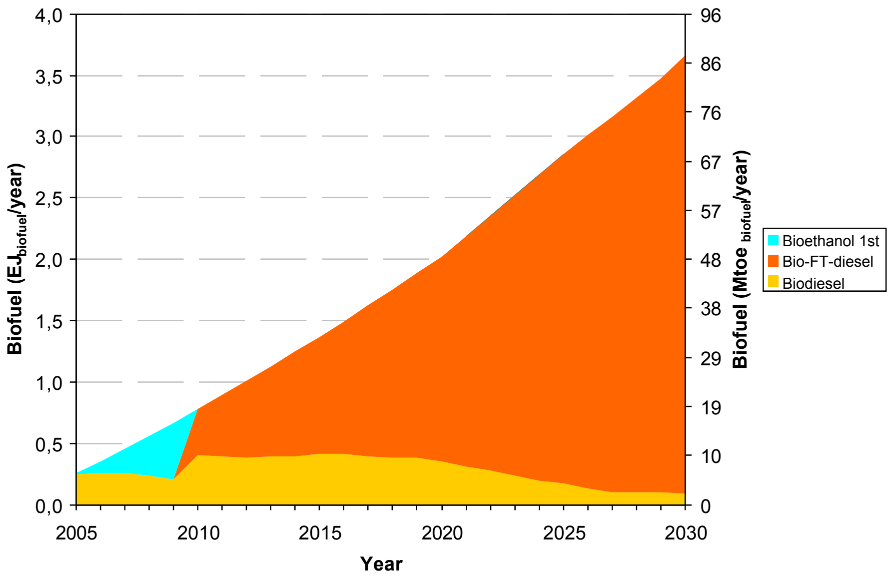

Figure 17: Biofuels mix in the case with a 60% reduction of feedstock potential.

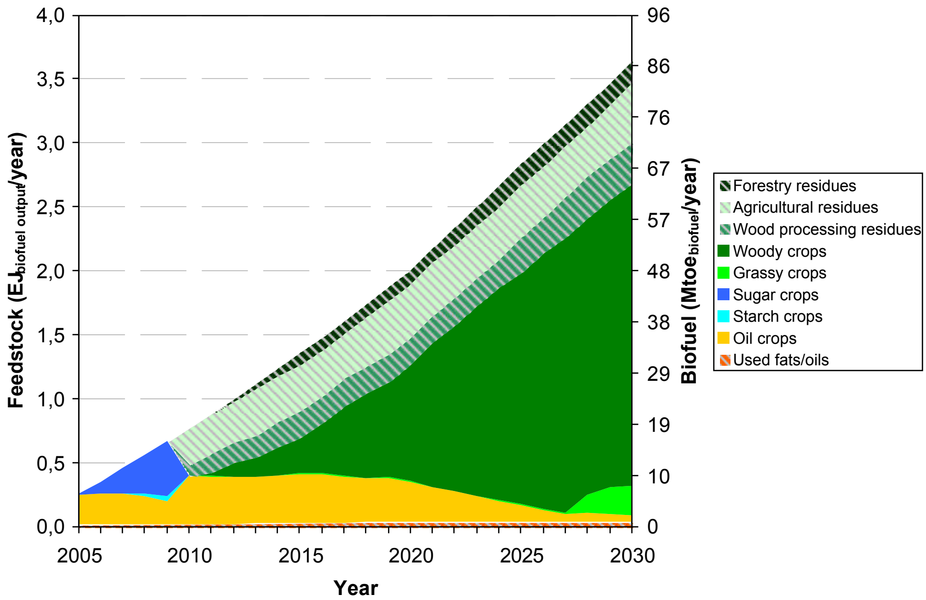

Figure 18: Feedstock mix in the case with a 60% reduction of feedstock potential.

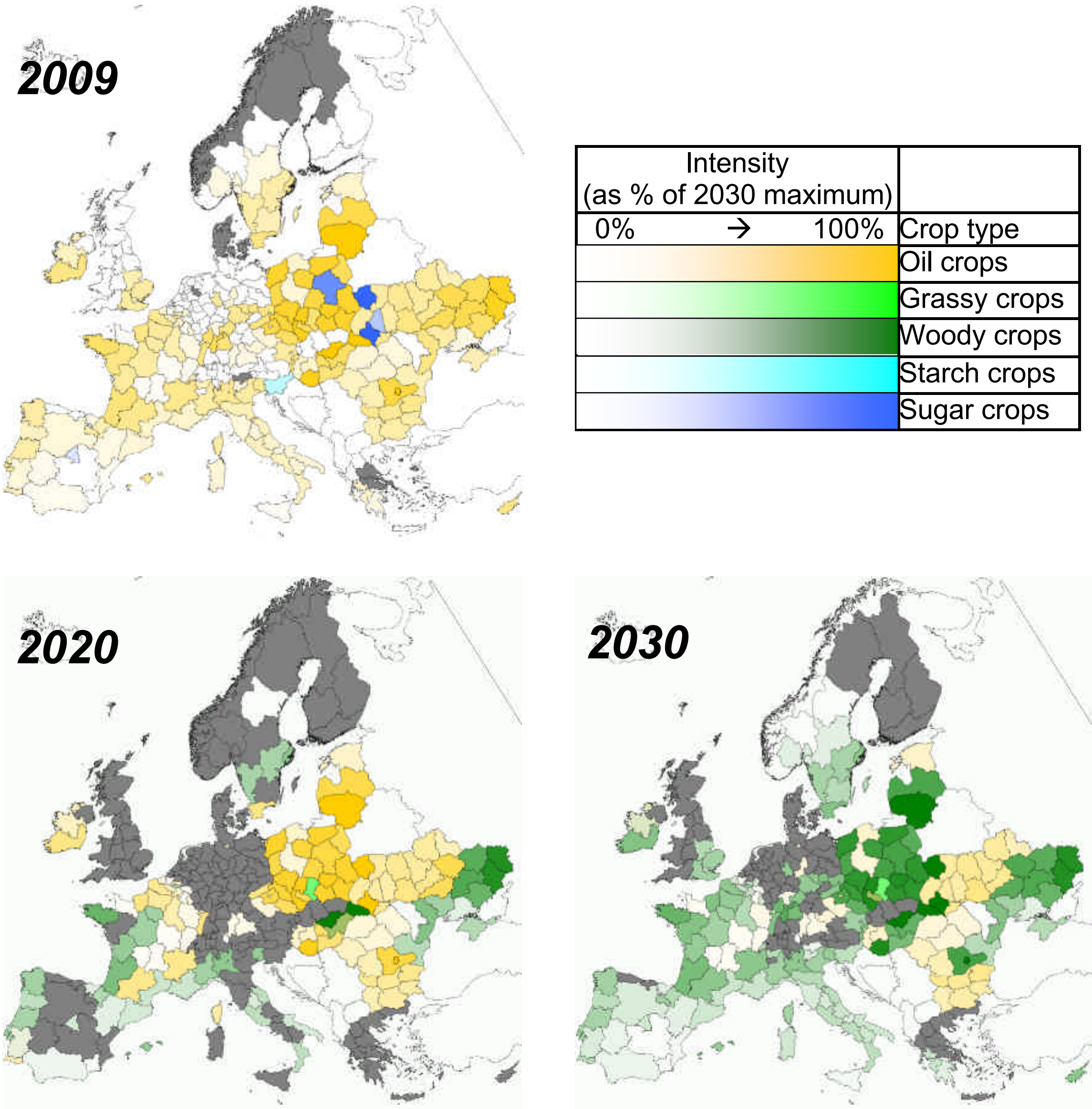

Figure 19: Crop cultivation in different EU regions in the analysis with an active RES-E/H policy and only 40% of feedstock potential available for biofuels.

In terms of average costs, biomass scarcity logically leads to the application of more costly residues and of the more expensive parts of the crop cost-supply curve. Furthermore, the scarcity of options with a high biofuel production per ha before 2010 leads to a more significant cost rise in these years. However, as the last bar in Figure 20 indicates, these cost increases are not very substantial in the long term: Even with only 40% of biomass potential available for biofuels, the additional costs compared to the standard high case are ca 10% by 2030.

In short, an active policy on other biomass applications leads to the introduction of more land-efficient biofuel chains, at additional costs. By 2030, advanced FT-diesel almost entirely dominated the biofuels mix, against additional costs of circa 10%. On the other hand, such a strong demand on biomass feedstock for biofuels, power and heat may lead to an overheated feedstock market, with price hikes that the methodology in Biotrans is less suitable to model.

4.7 Comparison of the costs and GHG impacts of the policy options

In this section, we describe the GHG impacts of the six specific policy measures described in sections 4.1 to 4.6: Allowing imports, CO_2 pricing, investment subsidies, energy crop premiums, specific targets for the gasoline and diesel markets, and an active RES-E/H policy leading to lower feedstock availability. Figure 20 shows the average biofuel costs by 2030 for these cases and the overall greenhouse gas emission reduction they lead to. In this graph, it shows that e.g. the case with CO_2 pricing leads to higher costs, but also has a better GHG performance because of the stronger introduction of 2nd generation biofuels. Imports lead to lower costs but also to somewhat lower GHG emission reductions because 2nd generation penetrate less strongly. Investment subsidies have a comparable effect as CO_2 pricing, while energy crop premiums induce relatively high costs and low GHG emission reductions. Quite striking is that the case with gasoline/diesel targets is relatively costly compared to its GHG emission reduction; again, the latter is relatively poor since there remains a higher share of biodiesel in the biofuel mix. Finally, the option with active RES-E/H policy and reduced feedstock potential for biofuels shows a more offensive introduction of 2nd generation biofuels because of land availability limitations. It has the best ratio between GHG performance and costs. Note, however, that here we compare greenhouse gas emission reductions with average *overall production costs* for biofuels, not with additional costs compared to fossil fuels. Therefore, the comparison is not a basis for the calculation of mitigation costs in terms of €/tonne CO_2.

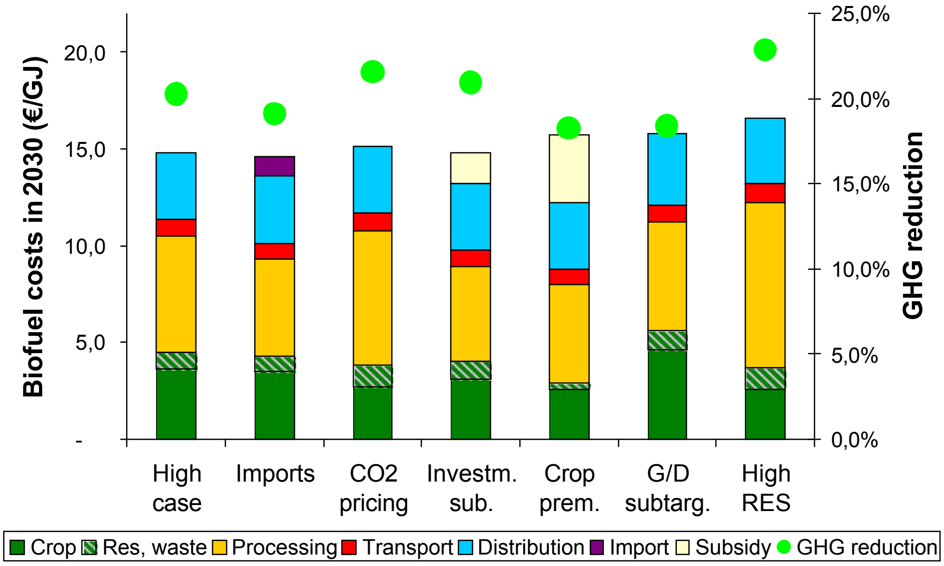

Figure 20: Biofuel costs and GHG emission reductions for the three policy cases and in a case with active RES-E/H policy.

On EU security of energy supply in the transportation sector, most of these policy cases have no other impacts than the 'standard' high case. Only two effects can be observed:

- In the import case, non-domestic biofuels are introduced in the supply mix, reducing EU domestic fuel supply for transport from the original 22.4% to 20.1%. However, as these imports originate from other regions than the dominant regions for fossil oil imports, these imports may be considered less problematic.
- In the active RES-E/H policy case, improvements in EU security of supply in the power and heat sector will be observed. This impact is not quantified any further in this study.

4.8 Biofuels target per country in stead of an overall EU target

In the standard analysis, all EU member states have to meet a biofuels target in each year. However, often EU targets are differentiated among member states. This approach is commonly known as 'burden sharing'. The best-known example is the EU greenhouse gas emission reduction target in the Kyoto protocol, which was differentiated among the EU member states taking into account *inter alia* differences in characteristics of the power generation sectors between member states. For biofuels, differences in potentials for biofuels feedstock in each country may be (part of) a basis for target differentiation. As an extreme variant, we therefore analysed the situation in which a biofuels target share is applied to the EU overall, and the model selects the most cost-effective national contributions in order to come to this overall target

As Figure 21 indicates, the allocation over the different EU member states significantly differs in a situation in which only an overall EU target is set, although the biofuel and resource mixes remain the same. Generally, countries with a high biofuel feedstock production potential come to high biofuel shares: most CEE countries can be found in the left part of the graph. Also, some countries close to areas with large production potential, such as Greece, can be found on this side. On the other hand, countries with a high fuel demand and hardly any domestic supply potential can be found on the right hand side. Note that in total, the same amount of biofuels is being produced in the burden sharing case as in the standard high case.

In general, such a burden sharing approach leads to negligible differences in the biofuels and feedstock mix: biodiesel and (later on) FT-diesel are the dominant biofuels. However, a slightly more cost-efficient fulfilment of the biofuels target could be observed with burden sharing: the average costs over the years are 0.2 to 0.3 €/GJ lower than in the standard high case. Note, however, that the *allocation* of costs among member state greatly differs among the member states (for details see the REFUEL WP6 report, (Duer et al., in prep.)). Greenhouse emissions in the burden sharing case are negligibly lower than in the standard high case, mainly because greenhouse gas emissions due to transport are not a major part of overall greenhouse gas emissions of biofuels.

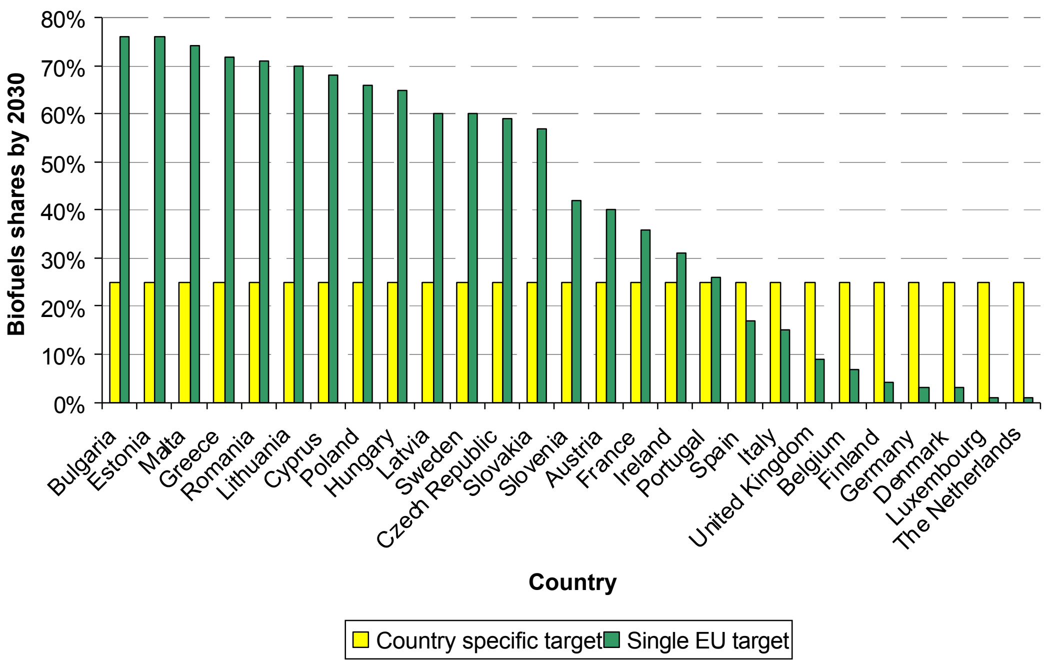

Figure 21: Biofuel shares by 2030 in a 'burden sharing' case.

In short, a burden sharing approach like this leads to:

- A substantial differentiation of biofuel shares among member states, with (on average) high shares in CEE countries and low shares in WE countries;
- Slightly lower average biofuels costs and slightly lower greenhouse gas emissions.

4.9 Feedstock trade in stead of biofuel trade

In the debate on biofuels in general and on 2nd generation biofuels in particular, these is some dispute on the set-up of the supply chains: should conversion installations be located close to the centres of feedstock production in order to keep feedstock transportation modest, or should they be located close to the distribution infrastructure, in order to be close to their blending facilities and markets? An additional issue here is that Western European countries currently may have a more attractive technology infrastructure and investment climate for the complex 2nd generation technologies than the Central and Eastern European countries.

Therefore, we analysed the impacts of an additional condition, i.e. that biofuels should be produced close to their markets, and feedstock in stead of fuels are transported through Europe. Such a case leads to some relatively minor differences in biofuel supply: the 2030 share of biodiesel is ca 10% higher than in the standard high case, at the expense of FT-diesel, and the feedstock base for FT-diesel starts using cultivated crops slightly earlier. On average, feedstock trade in stead of biofuel trade leads to average biofuel costs that are 1 €/GJ higher than in the standard high case. This could be considered the extra costs an importing country has to pay if it prefers to have the conversion capacity within its country borders.

5 Sensitivity analysis

An analysis of model outcomes with limited availability of feedstock shows that the ambitious 25% target for 2030 can even be met with only 40% of the total feedstock potential. While short term biofuels costs are significantly higher in such a case, long-term average biofuel costs are only ca 10% higher than in the standard high case. Due to limitations in land availability, conventional bioethanol play an important role in the years before 2010, at the expense of biodiesel with its low biofuel yields per ha. After 2010, more land-efficient 2nd generation biofuels take higher shares of the biofuels mix than in the standard high case, soon outcompeting conventional bioethanol, and gradually taking over the share of conventional biodiesel as well.

A Monte Carlo analysis varying the input parameters related to conversion processes only indicates that biodiesel will almost always play a role. Of the advanced biofuels, FT-diesel has the highest probability of entering the market, followed by 2nd generation bioethanol and DME. In general, if any of these advanced biofuels enters the market it does so in significant market shares, and combinations of two or more advanced biofuels are improbable. This is mainly because any advanced biofuel entering the market experiences cost reductions due to technological learning, thereby improving its competitiveness toward other advanced biofuel options. On the other hand, the biofuels market seems to be sufficiently large to allow introduction and learning-by-upscaling for more than one 2nd generation technology.

In order to analyse the robustness of the model outcomes, we performed a sensitivity analysis on both the available potential of feedstock (section 5.1), on the key parameters related to conversion technologies (section 5.2), and on the assumed costs of biofuel and feedstock imports (5.3).

5.1 Impacts of feedstock potential reduction

The standard analysis in this study assumes that the full potential of biomass feedstock is available for biofuels. It is beyond the scope of this study to analyse the competition for feedstock between these applications, but it does make sense to analyse what happens to biofuels when biomass potential is lower than originally assumed. Therefore, we ran Biotrans with structural reductions of *all* feedstock potentials (residues as well as land for crops) of 20%, 40%, 60% and 80% in each NUTS2 region. The reduction was applied over all parts of the cost-supply curve, so for each cost level, supply was reduced with the given percentages.

With increasing limitation, the share of bioethanol increases in the period before 2010, because this fuel chain has a higher biofuel productivity per ha than biodiesel (see Figure 17 for the situation with only 40% available). In later years, increasing feedstock limitation leads to a more dominant role of advanced FT-diesel. As for the resource mix, a wider variety of feedstock is applied with increasing feedstock limitation (see Figure 18 for the situation with only 40% available).

As Figure 22 indicates, feedstock costs increase with reducing overall feedstock potential. However, on the long term this effect is rather limited as long as the available resource base is 40%

or higher. Only when potentials are reduced to 20% or lower, the given biofuel targets cannot be met in all years by domestic production.

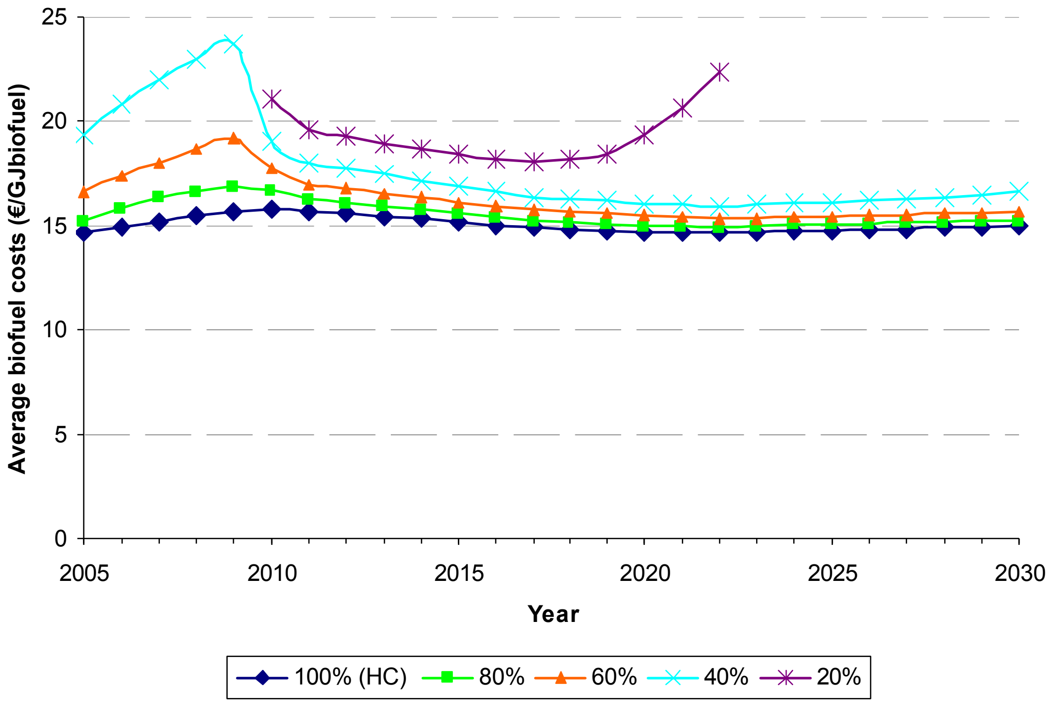

Figure 22: Increasing average biofuel costs with decreased feedstock potential.

5.2 Penetration of different biofuels in the Monte Carlo analysis

In addition to the variation in feedstock potentials, we carried out a Monte Carlo analysis over several input parameters in the model. As we purely considered this a sensitivity analysis, no scenario analysis, all parameters were varied randomly over 1803 runs, which appeared a sufficient amount of runs to approach a normal distribution in the total costs. Annex 2 shows the parameters that were considered, including their min, max and default values. The main end variable for the analysis was the probabilities for different biofuels to penetrate with a certain market share. Figure 6 already showed the probabilities of the different biofuels to enter the market; Figure 23 indicates this in a more refined manner. It shows the relation between a certain market share for a given biofuel and the probability that it will reach this share. For example, there is a 40% probability that FT-diesel will reach a market share of 70%. In general, it seems that biodiesel will always have a part in the biofuels mix: the probability for biodiesel having a market share of, say 5% is almost 100%. For the advanced biofuels FT-diesel, 2nd generation bioethanol and DME, the probability curves run rather flat: if any of these fuels are introduced, the fuel will start learning and thereby be able to take up a significant market share.

One other outcome of the sensitivity analysis is that in most cases only one of the advanced biofuel options enters the market. Only in 5% of the cases, a combination of FT-diesel and DME is introduced; in other cases it's only FT-diesel (60% of the cases), 2nd generation bioethanol (25%), and DME only (10%).

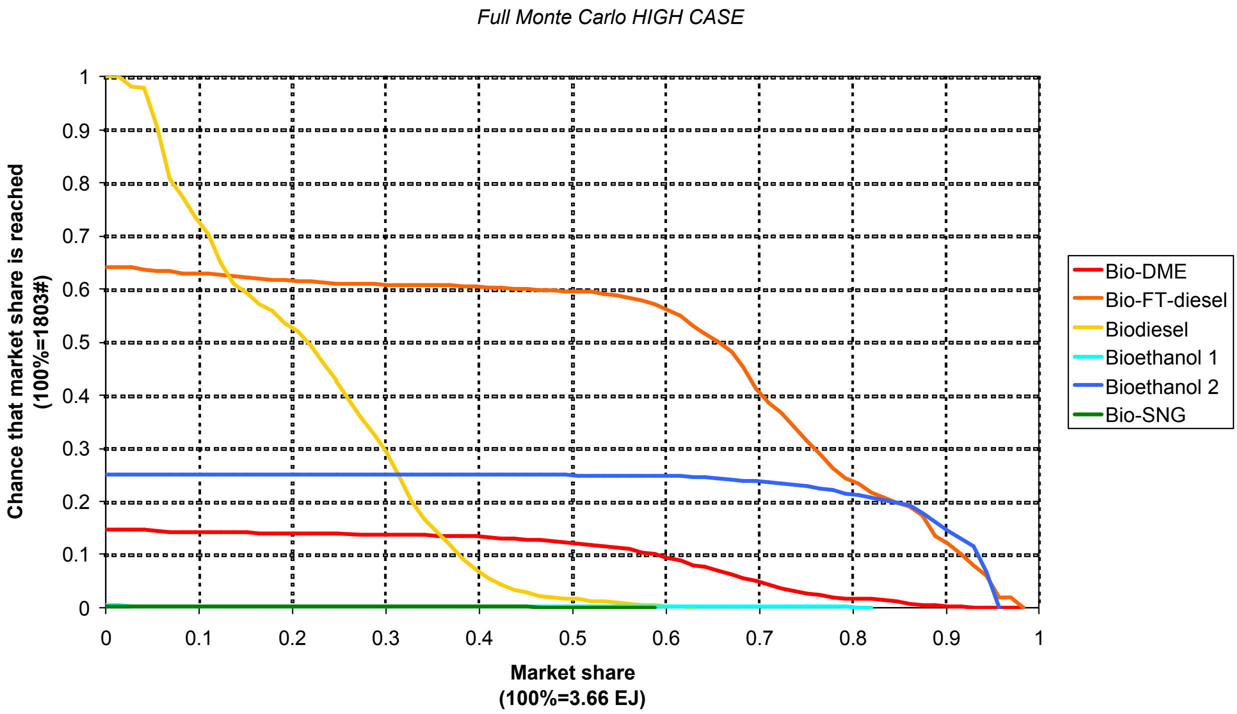

Figure 23: Probability/market share graph for the different biofuels.

5.3 Changes in import costs

In the light of the recent price hikes of agricultural commodities, vegetable oils in particular, it is relevant to analyse up to which price levels bioethanol and palm oil imports remain competitive.

At import price levels of 1.5 times the original assumptions, ethanol imports completely disappear from the biofuel mix (for the case with 'standard' costs for imports see Figure 7). Apparently, the break-even price for bioethanol to (temporarily) enter the biofuels mix lies between 13 and 19 €/GJ (or 280 and 400 €/m^3). The replacing biofuel in the mix is mostly 2nd generation FT-diesel.

For palm oil, two effects can be observed with increasing costs:

- At modest cost increases, the share of palm oil imports in the initial years (until 2014) is reduced significantly (see Figure 24). From 2015 on, the full potential of palm oil is applied in all analyses within this cost range.
- The full feedstock potential is applied until 2030 at cost levels up to 12.5 €/GJ (450 €/tonne). Above this level, palm oil starts phasing out after 2020, completely disappearing from the biofuel mix after 2025, being replaced by 2nd generation FT-diesel.

This comparison, however, should not be a basis for comparison with current market prices for palm oil and other feedstock. EU-production of feedstock in Biotrans is expressed in terms of production costs, not as an (equilibrium) market price (see 6.3).

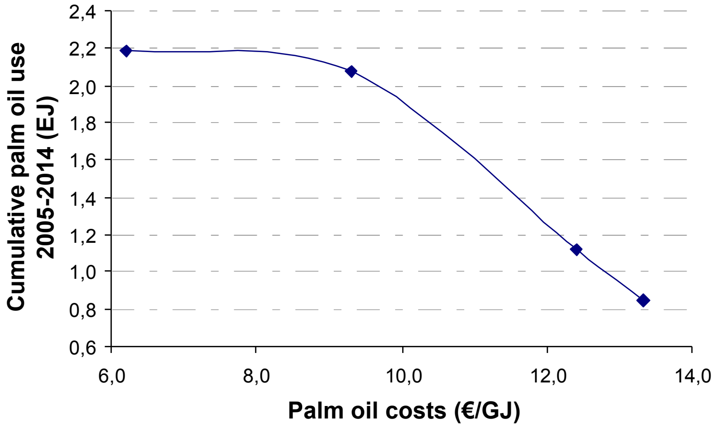

Figure 24: Cumulative use of palm oil 2005-2014 as a function of palm oil costs.

6 Conclusions

6.1 Specific conclusions for the different analyses

The analysis of the three 'standard' cases with increasing target levels for biofuels lead to the following conclusions:

- Increasing targets lead to a shift towards more land-efficient 2nd generation biofuels, and thereby also to more greenhouse gas savings (both in absolute terms and in avoided emissions per GJ of biofuel applied).
- The average costs per GJ biofuel only increase modestly with increasing targets. Between the high case and the baseline, the cost difference is 12%.
- With increasing target levels, the introduction of 2nd generation biofuels becomes more probable as low-cost feedstock availability becomes the limiting factor for biodiesel.
- Of the 2nd generation biofuels, FT-diesel has the highest probability of introduction, followed by 2nd generation ethanol. Furthermore, if a 2nd generation technology enters the mix, its cost reduction due to learning makes it less probable that another 2nd generation technology will enter as well.

Apart from the height of the target level, several other policies also have effects on the biofuels development pathway:

- Allowing imports leads to a lower and more stable average cost of biofuels, especially on the short term. It leads to a later introduction year of advanced biofuels. The greenhouse gas emission reduction in this variant is slightly lower, mainly because 2nd generation biofuels penetrate less strongly.
- Introduction of CO_2 pricing leads to an increase in 2nd generation biofuels production of ca 20%. As a consequence, the GHG profile of the fuel mix by 2030 is better, at the expense of a marginal cost increase.
- Introduction of investment subsidies for biofuel production also induces a shift in the mix towards 2nd generation biofuels because these fuels are more capital-intensive. This policy leads to a better GHG profile, against very limited additional costs. On the other hand, an energy crop premium (set per ha) induces a stronger role for biodiesel since feedstock is the dominant factor in the cost build-up of this fuel. This policy leads to a poorer GHG profile against significantly higher costs of around 1 €/GJ.
- Introduction of subtargets for gasoline and diesel substitutes induces conventional bioethanol to enter the mix in the initial year. After 2010 lignocellulosic ethanol enters the mix, to be followed by FT-diesel around 2025. Overall fuel costs in the 2005-2030 period are structurally higher than in the standard high case, and since biodiesel maintains a higher share in the mix than in the standard high case, the GHG emission reductions are lower.
- An active policy on renewable energy for power and heat leads to a reduction of available feedstock for biofuels. This feedstock reduction urges a stronger penetration of 2nd generation biofuels (FT-diesel). Initially, this leads to significantly higher costs, but by

2030 the cost increase is less than 10% compared to the standard high case. As first generation biodiesel is largely phased out, this fuel mix has the strongest GHG emission reduction.

- Burden sharing leads to major shifts in biofuel shares between member states, with limited overall cost reductions in the order of 0.2 €/GJ.

- A strategy in which conversion technologies are located close to the regions with high fuel demand in stead of the regions with high feedstock supply leads to a biofuel cost increase of about 1 €/GJ.

6.2 General conclusions

In almost all analyses with targets higher than the baseline, 2nd generation biofuels enter the mix sooner or later. The share of these fuels in the mix also strongly determines both the overall costs of biofuels (increasing with increasing share of 2nd generation) and the greenhouse gas emission reductions (also increasing with increasing share of 2nd generation). The ratio between 1st and 2nd generation biofuels can be influenced in roughly three ways:

- Generally, a higher target leads to an increase in the share of 2nd generation biofuels in the mix.
- Limitation of the feedstock base has a comparable effect, and extension of the feedstock base by imports induces a contrary effect.
- Subsidies and CO_2 pricing mechanisms have impacts according to the differences in cost structures of the different biofuels: investment subsidies and CO_2 pricing enhance 2nd generation biofuels with their high capital costs and high GHG emission reductions, while an energy crop premium per ha enhances 1st generation biofuels with their high feedstock costs.

Furthermore, biofuel costs do not vary very strongly over time, not even when the biofuels target increases strongly. This is due to two countervailing mechanisms: on one hand, an increasing target leads to application of higher parts of the cost-supply curve for biomass feedstock, inducing higher costs. On the other hand, especially 2nd generation conversion technologies reduce costs over time due to technological learning. In many cases these two effects balance each other out almost completely.

A (moderate) specific subtarget for 2nd generation biofuels does not lead to significantly different results in most model runs. Such a subtarget does not seem to be necessary when a high biofuel target, possibly combined with a CO_2 pricing mechanism and ambitious targets for RES-E/H, is in place. On the other hand, the combination with subtargets for gasoline and diesel substitutes shows that there is a significant probability that 2nd generation biofuels do not enter the market; in such a case, a subtarget for 2nd generation biofuels would be a back-up measure to ensure their introduction.

6.3 Limitations

When interpreting the results and conclusions presented here, there are some essential limitations of our approach that should be borne in mind.

- The Biotrans model calculations are based on production costs, for conversion technologies as well as for feedstock. In practice, both will operate in dynamic markets. First, a price for feedstock in a completely free and transparent market will be based on the cost of the marginal unit applied; against this price all feedstock will be traded. The approach in Biotrans, in which all feedstock is traded against its specific production costs, entails significantly lower costs. Such costs may be a approximated in a market with mostly bilateral trading in which a limited number of dominant buyers can set differentiated prices close to the specific production costs of individual small suppliers (price discrimination). While agricultural commodity markets often show this type of characteristics, price levels in practice may be somewhere between the extremes of a completely open market and a situation with full price discrimination.

- Second, biofuel feedstocks, which relate to (agricultural) commodity markets, may face significant price volatility due to developments in global feedstock demand for other applications, and in supply. Examples are increasing food and fodder demand in regions such as China and India and variations in harvests between years. The approach taken here, in which demand for food is first projected, and remaining land areas are allocated to bioenergy feedstocks, does not take into account such cross-sector influences on commodity prices. Due to these two limitations, the costs as indicated in this report are not related to any short-term market prices for feedstocks, and only a very limited proxy for long-term equilibrium prices.

- These limitations apply to EU-domestic feedstock production as well as imported biofuels and feedstocks. The 2007 price peak of many agricultural commodities shows that many factors not related to biofuels strongly affect these costs, as confirmed in the recent OECD-FAO agricultural outlook (Anonymous, 2007a).

- The Biotrans model optimizes to a least-cost fuel mix meeting a given demand for biofuels. This leads to quite radical choices between biofuel chains, also when the cost differences between the chains are relatively minor. Reality will not behave in this manner, at least for two reasons. First, there will always be specific niche situations in which a biofuel chain that is slightly more expensive in our (aggregated) analysis has specific benefits over the chain that has slightly lower cost according to our data. Furthermore, investors will not always have perfect information on the costs of different options, and with small differences between two options, both will probably be developed. This also implies that the strong dominance of biodiesel and FT-diesel in our proposed pathways is too simplified: in the short-term reality both biodiesel and bio-ethanol are being deployed; in the future FT-diesel and lignocellulosic ethanol may be developed, and possibly DME and/or SNG as well. At least, the biofuels market will be sufficiently large to allow the entrance of more than one of these technologies and their subsequent learning-by-upscaling.

- Finally, our analysis has not taken into account any issues related to the integration of biofuels into the current and future EU refinery capacity. As EU refineries currently produce a surplus of gasoline and a shortage of diesel, a diesel-substituting biofuel may be more attractive for oil companies in the short term. On the other hand, a biofuels mix producing only diesel substitutes in the long term, such as many of our pathways, may create a reversal of this situation in the future. These types of effects, and their implications for e.g. biofuel costs, have not been included into our analysis.

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Annex 1: Greenhouse gas emission data used in Biotrans

Biofuel	Feedstock	Emissions <2010 (kg CO_2-eq/$GJ_{biofuel}$)	Emissions 2010-2020 (kg CO_2-eq/$GJ_{biofuel}$)	Emissions >2020 (kg CO_2-eq/$GJ_{biofuel}$)
Biodiesel	Rapeseed	49,2	48,8	45,3
	Sunflower	26,2	26,8	26,8
	Used fats/oils	42,2	36,5	30,5
	Palm Oil (imported)	42,2	36,5	30,5
Bio-DME	Agricultural residues	3,3	3	3,1
	Forestry residues	6,6	5,8	5,7
	Grassy crops	12	11	11,6
	Wood processing res.	3,7	3,2	3,3
Bio-DME	Woody crops	8,7	8,1	8,5
Bioethanol 1st	Maize	60,3	63,2	62,1
	Rye	60,9	38,4	17
	Sorghum	11,5	11,2	11,7
	Sugar beet	58,4	58,5	58,9
	Triticale	60,1	37,5	16,6
	Wheat	59,9	38,9	17,2
	Imported	11,5	11,2	11,7
Bioethanol 2nd	Agricultural residues	9,6	10,1	9,8
	Forestry residues	18,7	19,2	19
	Grassy crops	27,6	27,2	27
	Wood processing res.	10,3	10,3	10,2
	Woody crops	22,5	22,9	22,7
Bio-FT-Diesel	Agricultural residues	3,4	3,1	3,2
	Forestry residues	6,6	5,7	6,2
	Grassy crops	12,2	11,2	11,7
	Wood processing res.	3,7	3,2	3,4
	Woody crops	9,3	8,5	8,2
Bio-SNG	Agricultural residues	3,1	2,9	3,2
	Forestry residues	6,1	5,3	6,5
	Grassy crops	11,3	10,3	11,9
	Liquid manure	-75,4	-76,4	-76
	Wood processing res.	3,4	3	3,4
	Woody crops	8,3	7,6	8,2

Annex 2: Variations in input parameters in the Monte Carlo sensitivity analysis (high case)

1. Technical parameters in conversion technologies

ProcessId	Arithmetic value	Minimum	Maximum	Unit
Biogas production	**7500**	6000	8760	[h/yr]
Cellulose-EtOH	**8000**	7000	8760	[h/yr]
DME production	**8000**	7000	8760	[h/yr]
FT production	**8000**	7000	8760	[h/yr]
Oil extraction	**8000**	4000	8760	[h/yr]
Pre-tr. (TOP)	**8000**	7000	8760	[h/yr]
SNG production	**8000**	7000	8760	[h/yr]
Starch-EtOH	**8000**	6000	8760	[h/yr]
Sugar-EtOH	**8000**	6000	8760	[h/yr]
Transesterif-oil seed	**8000**	6000	8760	[h/yr]
Transesterif-used-fat	**8000**	6000	8760	[h/yr]

Full load hours

ProcessId	Arithmetic value	Maximum	Minimum	Unit
Biogas production	**20**	20	10	[yr]
Cellulose-EtOH	**20**	25	15	[yr]
DME production	**20**	25	15	[yr]
FT production	**20**	25	15	[yr]
Oil extraction	**20**	20	10	[yr]
Pre-tr. (TOP)	**10**	15	10	[yr]
SNG production	**20**	25	15	[yr]
Starch-EtOH	**20**	20	10	[yr]
Sugar-EtOH	**20**	20	10	[yr]
Transesterif-oil seed	**20**	20	10	[yr]
Transesterif-used-fat	**20**	20	10	[yr]

Life time

ProcessId	Arithmetic value	Minimum	Maximum	Unit
Biogas production	**0,34**	0,20	0,70	[GJoutput/GJinput]
Cellulose-EtOH	**0,39**	0,35	0,47	[GJoutput/GJinput]
DME production	**0,56**	0,45	0,65	[GJoutput/GJinput]
FT production	**0,53**	0,40	0,60	[GJoutput/GJinput]
Oil extraction	**0,39**	0,35	0,42	[toutput/tinput]
Pre-tr. (TOP)	**0,95**	0,90	0,98	[GJoutput/GJinput]
SNG production	**0,63**	0,50	0,70	[GJoutput/GJinput]
Starch-EtOH	**0,35**	0,30	0,40	[toutput/tinput]
Sugar-EtOH	**0,29**	0,24	0,34	[toutput/tinput]
Transesterif-oil seed	**1,00**	0,95	1,02	[toutput/tinput]
Transesterif-used-fat	**1,00**	0,90	1,02	[toutput/tinput]

Conversion efficiencies

2. Cost parameters for conversion technologies

ProcessId	Arithmetic value	Minimum	Maximum	Unit
Biogas production	**6,35**	3,80	8,90	[EUR2002/GJinput/yr]
Cellulose-EtOH	**71,42**	43,00	100,00	[EUR2002/tinput/yr]
DME production	**35,56**	21,00	50,00	[EUR2002/tinput/yr]
FT production	**41,83**	25,00	59,00	[EUR2002/tinput/yr]
Oil extraction	**26,61**	16,00	37,00	[EUR2002/tinput/yr]
Pre-tr. (TOP)	**28,32**	23,00	54,00	[EUR2002/tinput/yr]
SNG production	**41,83**	25,00	59,00	[EUR2002/tinput/yr]
Starch-EtOH	**92,20**	55,00	130,00	[EUR2002/tinput/yr]
Sugar-EtOH	**67,20**	40,00	94,00	[EUR2002/tinput/yr]
Transesterif-oil seed	**80,60**	48,00	110,00	[EUR2002/tinput/yr]
Transesterif-used-fat	**88,66**	53,00	120,00	[EUR2002/tinput/yr]

O&M costs

ProcessId	Arithmetic value	Minimum	Maximum	Unit
Biogas production	**31,74**	19	44	[EUR2002/GJinput/yr]
Cellulose-EtOH	**712**	430	1000	[EUR2002/tinput/yr]
DME production	**593**	360	830	[EUR2002/tinput/yr]
FT production	**697**	420	980	[EUR2002/tinput/yr]
Oil extraction	**102,5**	72	130	[EUR2002/tinput/yr]
Pre-tr. (TOP)	**92,38**	55	130	[EUR2002/tinput/yr]
SNG production	**697**	420	980	[EUR2002/tinput/yr]
Starch-EtOH	**264**	180	340	[EUR2002/tinput/yr]
Sugar-EtOH	**163**	110	210	[EUR2002/tinput/yr]
Transesterif-oil seed	**200**	140	260	[EUR2002/tinput/yr]
Transesterif-used-fat	**300**	210	390	[EUR2002/tinput/yr]

Investment costs

3. Parameters for by-products

ProductName	ProcessId	Arithmetic value	Minimum	Maximum	Unit
Electricity	Cellulose-EtOH	**0,475**	0,35	0,95	[MWh/tinput]
Electricity	DME production	**0,15**	0	0,3	[MWh/tinput]
Electricity	FT production	**0,15**	0	0,3	[MWh/tinput]
Pulp (from oil seeds)	Oil extraction	**0,59**	0,55	0,61	[t/tinput]
Electricity	SNG production	**0,15**	0	0,3	[MWh/tinput]
Stillage	Starch-EtOH	**0,2806**	0,2	0,4	[t/tinput]
Pulp (from sugar crops)	Sugar-EtOH	**0,3107**	0,2	0,4	[t/tinput]
Vinasses	Sugar-EtOH	**0,1157**	0	0,2	[t/tinput]
Glycerine (80%)	Transesterif-oil seed	**0,1125**	0,08	0,12	[t/tinput]
Glycerine (80%)	Transesterif-used-fat	**0,1013**	0,08	0,12	[t/tinput]

Yields of by-products

4. Parameters describing technological learning in conversion

ProcessId	Progress Ratio	Min	Max
Biogas production	**0,90**	0,80	0,97
Cellulose-EtOH	**0,99**	0,95	1,00
DME production	**0,98**	0,95	1,00
FT production	**0,98**	0,95	1,00
SNG production	**0,98**	0,95	1,00
Starch-EtOH	**0,80**	0,70	0,97
Sugar-EtOH	**0,80**	0,70	0,97
Transesterif-oil seed	**0,90**	0,80	0,97
Transesterif-used-fat	**0,90**	0,80	0,97
Progress ratios			

spvt	MaxScale	MaxMarketShare	DoublingTime
min	2000	2,5%	3
max	10000	25%	7
val	**3200**	**5%**	**5**
	MW	*market volume*	*year*

Contact refuel
Energy research Centre
of the Netherlands (ECN)
P.O. Box 1
1755 ZG Petten
The Netherlands
refuel@ecn.nl
www.ecn.nl/refuel

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refuel