QUICK SCAN LOCAL EMISSIONS BIOFUEL SCENARIOS

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1 Introduction

1.1 Background

With policy measures that stimulate the use of alternative energy, it is possible that along the supply chain, non-climate related emissions will increase in comparison with the fossil fuel reference. The BOLK project, led by the Netherlands Environmental Assessment Agency, analyses those effects on the middle term in a two staged project:

- Inventory phase:
  - Estimation of the alternative energy sources that will be present in 2020;
  - Inventory of what effects can be expected;
  - Development of methods to quantify the effects;
  - Initial quantification of the effects;
- In-depth analysis phase:
  - More factors will be taken into account that determine the 2020 situation;
  - More detailed quantitative analysis, with recognition of technological improvements along the supply chain towards 2020.

This report considers the inventory phase; it is a quick-scan with the aim to give directions to in-depth research in the second phase of the BOLK project.

This report is a part of the BOLK project and focuses entirely on the use of solid and liquid biofuels for transportation and stationary application. This use leads to local emissions of, amongst others, NEC (National Emission Ceiling) components in all stages along the supply chain. Examples of these are:

- NO_x and amonia emissions resulting from the application of fertiliser during the feedstock production stage;
- SO_x, NO_x and particle matter emissions from the use of machinery and during transportation;
- Various emissions from CHP installations in biofuel factories;
- Increase of volatile organic compound emissions while blending biofuels with conventional fuels.

This study will analyse the effects of the *supply chain* (well-to-tank) of solid and liquid biofuels in 2020 with respect to emissions of classical air polluting substances (SO_2, NO_x, NH_3, NMVOS, PM_{10} en $PM_{2.5}$), inside and outside the Netherlands. In a parallel project, CE and TNO analyse the end-use effects (tank-to-wheel) of liquid biofuels application. This is depicted in Figure 1-1.

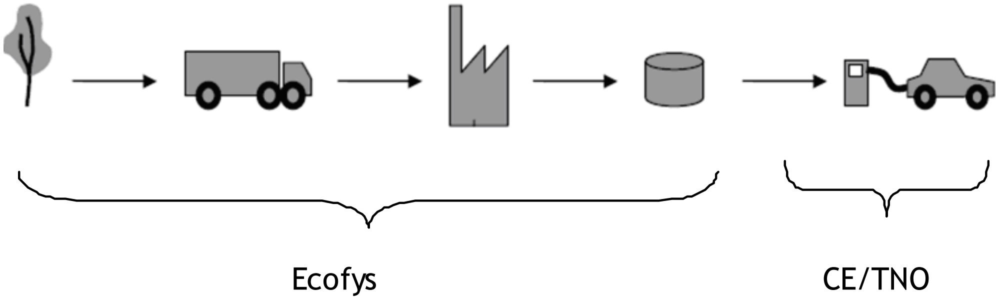

Figure 1-1: Overview of phases in biofuel chain and division of research.

1.2 Structure

The study consists of three parts:

- Selection of representative biofuels in the 2020 context by an analysis of the factors of influence on the biofuels spectrum in 2020;
- Modelling the supply chains for these biofuels (using SimaPro), to determine the amount of classical air polluting emissions;
- Determine the geographical location of the emissions.

The structure of the report is similar to the set up of the research and is given as follows:

- In Chapter 2 a short introduction to the broad variety biofuels that exist or are under development is given. Most biofuels in turn can be produced from many different feedstocks. Both biofuels for transport and for stationary applications are described;
- In the following chapter (Chapter 3) the major technical, economical, social and environmental factors influencing the biofuel spectrum and its feedstock in 2020 are described. Several crop-fuel combinations are selected for further study;
- In Chapter 4 the life cycles of the chains selected in Chapter 3, are modelled up to the point of sale (excluding end use). The results regarding effects on local air quality are given and divided per main geographical region (World, EU, Netherlands);
- Finally in Chapter 5, the main conclusions are presented and recommendations for further research are given.

2 Biofuel chains

The main biofuels are described, indicating the conversion routes, feedstock and main characteristics. The overview of the various biofuels is divided in those currently commercially available and those which will become commercially available on the middle long term.

2.1 Overview

In general, a small number of typical conversion routes are available to produce biofuels for transport from certain feedstock. An overview of these main routes (fermentation, gasification, extraction, hydrolysis or digestion) is given in Figure 2-1. As a result of these conversion routes a whole range of biofuels, like bio oil, biodiesel, bioethanol, synthetic diesel or methanol, can be produced. Some of these biofuels are already currently in production and available, like bio oil, biodiesel, bioethanol and ETBE. Regarding other fuels (among which ethanol from lignocellulose biomass, Fischer-Tropsch diesel, substitute natural gas and hydrogen) conversion routes are still under development and production is expected for the middle or long term.

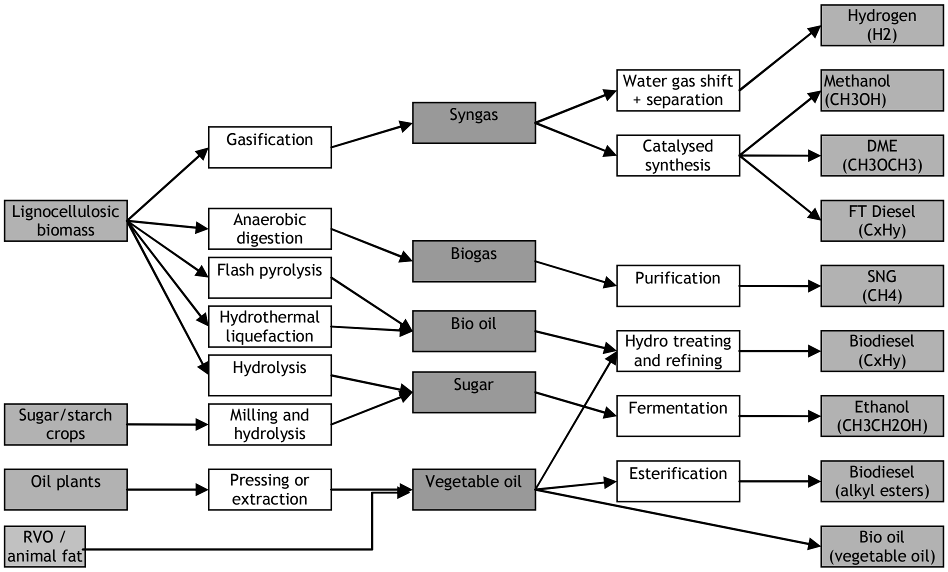

Figure 2-1. Overview of conversion routes from feedstock to biofuel (Hamelinck 2004).

In the transport sector, biofuels can be used to replace diesel or gasoline or both. Bioethanol and its derivative ETBE and biodiesel are currently the most widely applied biofuels. Towards the future a broad range of options is possible. The exact composition of the biofuels spectrum depends on many factors as described in the next chapter.

2.2 Currently available biofuels

Biodiesel

Biodiesel is commonly produced from vegetable oils, from oil palm, rapeseed, soybeans, etc. The vegetable oils are converted through transesterification in methyl esters which can be used as diesel. In this process glycerol is produced as a main by-product.

In principle, biodiesel can be blended with conventional diesel in any ratio. The use in the mainstream market is currently limited to 5% (volume), which will be increased to 10%. In fleets the fraction of biodiesel can be higher, up to 100%.

Some characteristics of biodiesel differ from conventional diesel and therefore may require adaptations in current infrastructure in case of large scale use. The oxidative stability is limited and therefore it cannot be stored for long periods. Depending on the feedstock, the low temperature behaviour can limit the application (higher viscosity, occurrence of filter plugging)

Bioethanol

Bioethanol is produced by fermentation of sugars. These sugars can be extracted from feedstock like sugar beet and sugar cane or the sugars can be made from starch in crops like wheat, maize or potatoes. Besides from these crops sugars might also be extracted from residues like potato waste. Bioethanol in principle is not different from ethanol produced from non biomass feedstock. Differences between ethanol and bioethanol mainly result from differences in production processes (for example impurities).

Ethanol is most commonly used as low blends in gasoline, or as its derivative ETBE (see next section). Higher blends with gasoline are possible in Flexible Fuels Vehicles. Ethanol in pure form can also be used a replacement for diesel (Stockholm busses).

Some specific characteristics should be taken into account when bioethanol may be used as replacement or additive to conventional gasoline. The energy content on volume basis is significantly lower than that of gasoline. Ethanol is hygroscopic, i.e. it attracts water. Water in an ethanol/gasoline blend can lead to phase separation. Also, the addition of ethanol in low blends to gasoline increases the vapour pressure. Therefore, before blending takes place, the gasoline is adapted to a lower vapour pressure.

ETBE / MTBE

Ethyl or Methyl-tertiary-butyl ether is a derivative of ethanol or methanol (see below). The production process uses isobutylene in a catalytic reaction. ETBE and MTBE can only be used as a fuel additive (limited to 15% by volume) and not as a biofuel in pure form.

On the other hand, in low blends, M/ETBE does not have the hygroscopic or vapour pressure disadvantages of ethanol. For that reason, about 75 % of the ethanol is currently applied in the form of ETBE, and only 25 % in the form of ethanol.

Since the ether partially originates from isobutylene, which is of fossil origin, only part of it is counted as a biofuel (47 % for ETBE, 36 % for MTBE).

2.3 Promising biofuels for middle long term

Several types of biofuels are currently under development and could become available on the middle or long term. Most of the technologies focus on converting lignocellulose biomass into biofuels, which could result in lower production costs (mostly due to the fact that they use cheaper bioenergy crops and residues) and could result in higher greenhouse gas reductions.

Fischer Tropsch diesel

Fischer-Tropsch diesel (FT-diesel), also known as Biomass-to-Liquids (BTL) is produced from synthesis gas. Synthesis gas ($CO + H_2$) is produced by gasification of biomass. The biomass used for this process is mainly woody biomass because of its uniformity and possible low costs.

A disadvantage of the process is that it is very sensitive to fluctuations in biomass quality and contaminations in the feedstock. This also results in the main obstacles for economic introduction of the technology, which is the cleaning of the synthesis gas.

Methanol

From synthesis gas, by using another catalyst, it is also possible to produce methanol. Methanol can be applied in low blends with regular gasoline, in higher blends in flexible fuels vehicles and as MTBE (see above). Also, methanol is a component in the production of biodiesel.
Also the production process of methanol is very sensitive to fluctuations in biomass quality and contaminations in feedstock, like the Fischer-Tropsch process.

Ethanol by hydrolysis-fermentation

The cellulose and hemicellulose content of lignocellulose biomass (wood for example) can be converted into sugars. These sugars can then be fermented into ethanol. The main difference with current ethanol production is that the feedstock has to be pre-treated to liberate the sugars. Pre-treatment can be done by means of enzymatic and chemical processes (like hydrolysis).

An advantage of this technology is that lignocellulose biomass can be for example low costs woody biomass residues.

The main obstacles with this technology are the absence of an enzyme technology which is able to convert the sugars and which is economically attractive. Further large amounts of waste are still being generated at the production of ethanol from lignocellulose biomass.

Hydrotreated Vegetable Oil

Several oil companies (e.g. Neste Oil, ConocoPhillips and UOP) have developed a technology to catalytically hydrogenate bio-oil analogous to fossil oil. The plant oil triglyceride is converted into the corresponding alkane. As the glycerol chain of the triglyceride is hydrogenated to propane, there is no glycerol side stream. The process removes oxygen from the oil so that the resulting fuel is not an oxygenate.

HVO has specifications very close to that of conventional diesel, and can thus be used as a direct replacement.

Due to its similarity with conventional diesel the use of HVO requires no modifications or special precautions for the engine. Furthermore the production process does not use methanol and does not produce glycerine.

Substitute Natural Gas

In gasification process, synthesis gas is produced which can later be converted into methane (natural gas). Substitute natural gas functions in the same way as normal natural gas. A separate tank and fuelling points would be necessary for its large scale introduction. Further driving distances are shorter due to lower energy content.

2.4 Biofuels for stationary application

Some of the feedstock or intermediate products mentioned in Figure 2-1 are commonly used for stationary heat and/or power production. These are especially wood (waste) materials and the economically most attractive vegetable oils. Considering the high yield per hectare palm oil will probably keep a prominent role, provided that it comes from a sustainable source and that indirect negative effects are avoided.

3 Dutch biofuel spectrum in 2020

3.1 Main factors of influence

To generate a picture of the Dutch biofuel spectrum in 2020 it is necessary to indicate the main factors that influence its composition. The factors of influence taken into account are:

- The development of the transport market;
- The development of stationary applications;
- The potential supply of feedstock;
- The overall yields, costs, greenhouse gas savings and energy use.

They will be analyzed in the following section.

Biofuels targets

The European Commission has formulated the following targets for biofuels as fraction of the total market of transportation fuels:

- 2 % in 2005;
- 5.75 % in 2010;
- 10 % in 2020.

The targets are formulated on energy basis. Targets for 2005 and 2010 are indicative, which means that Member States had the flexibility to set their own, deviating targets.

The 2020 target (draft Renewable Energy Directive) will be binding. The commission also sets requirements to the sustainability, which will influence both the general choice of biofuels feedstock and the set-up of individual supply chains (see below).

Development transport market

The European transport fuels market faces a relative shortage of diesel in comparison with gasoline. This is the main reason why oil companies are searching for diesel replacement rather than gasoline alternatives.

The following graph,

Figure 3-1, shows the estimated volumes of biodiesel and bioethanol applied in the world for the period 2005-2015. The graph shows that the share of biodiesel and bioethanol will increase until almost 5% in 2015.

The graph shows expectations on world scale, where ethanol plays a major role (cheaper). Within Europe it is expected that biodiesel will be applied on a larger scale than bioethanol. There are several reasons for this. First of all biodiesel has lower investment costs. Bioethanol is cheaper on a world scale but due to import regulation and costs it is more expensive within Europe than biodiesel. So within Europe it will be 'cheaper' to use biodiesel.

Secondly there exists a gasoline surplus inside Europe, which will not stimulate the use of bioethanol. Thirdly biodiesel can be inserted in current infrastructure more easily. Bioethanol insertion in current infrastructure is more difficult due to problems with vapour pressure.

If no government stimulation is applied, the market within Europe will choose for biodiesel.

Therefore overall it is expected that biodiesel will be favoured within Europe but bioethanol will play a more prominent role outside Europe.

The commercially available biofuels already possess a considerable market share. In the following figure (

Figure 3-1) it is shown that the growth of the volume of biofuels and its share in the global fuel market increased very rapidly from 2005 onwards. It is expected that the growth of the share of biofuels will slow down in a couple of years. The current biofuel chains will then already have secured their market share and therefore the share for new commercially available (more advanced) biofuel chains will not yet be very large in 2020.

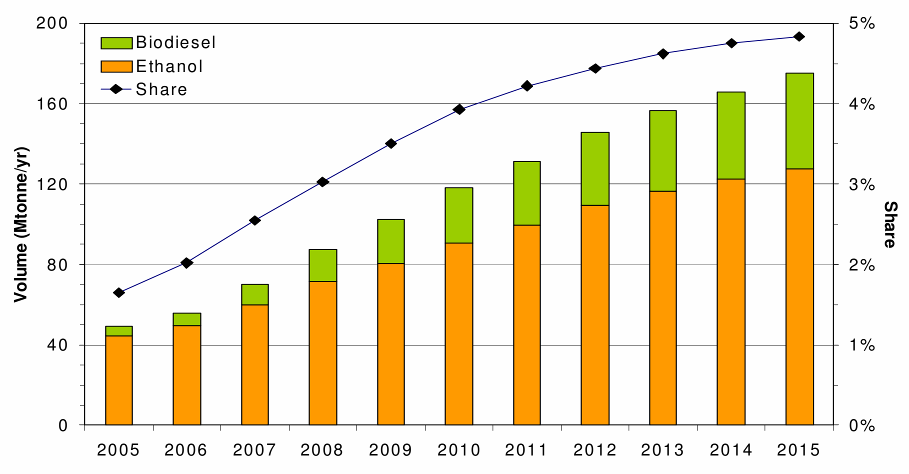

Figure 3-1: Estimated volumes of biodiesel and bioethanol used in perioduntil 2015 (Benigni 2007).

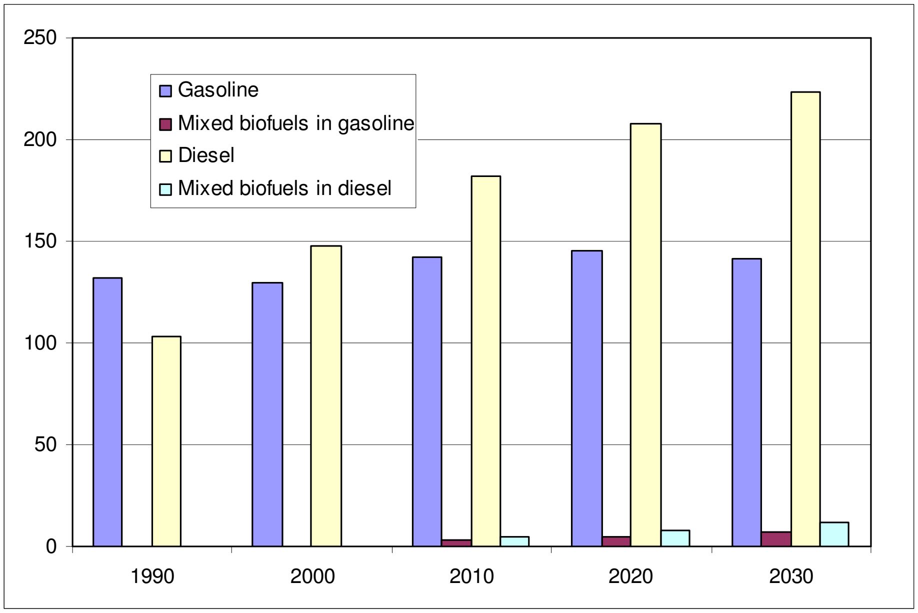

Figure 3-2: The development of gasoline, diesel, ethanol and biodiesel contribution to the transport sector, EU-25 (EC 2003).

Development stationary applications

Stationary applications are less dependent on the actual quality of the fuel than the automotive applications are. Further the logistic system is more flexible in including different types of materials or choices of materials. Therefore the choice of materials for stationary applications in 2020 is likely to consist of a broad range of feedstock.

The development of stationary applications for heat and electricity is mainly influenced by subsidy schemes and policies. At the moment production of electricity with the use of biofuels is still relatively expensive compared to the use of fossil fuels. Therefore subsidy schemes continue to largely influence the developments in these applications.

Lignocellulose biomass in 2020 will come from a broad range of sources such as forestry residues and dedicated energy crops. Solid wastes from various biomaterial processes (sugar cane bagasse or palm kernel shell) may be used for stationary applications either directly or after pre-treatment.

Supply of feedstock

The production of biofuels could be limited by the amount of feedstock available on a global level. Several academic studies have been conducted on the availability of biomass feedstock which forecast the amount of biomass which could be used for energy purposes. Results from these studies vary a lot depending on assumptions made. As an example, a number of studies with their results:

- GRAIN 2003: range 0 – 1135 EJ (Hoogwijk et al 2003);
- Hoogwijk 2004: 177 – 438 EJ below 4$/GJ depending on the chosen IPCC scenario (Hoogwijk 2004);
- Ecofys/MNP 2007: 90 EJ (4000 Mtonne) for logic supply chains (Hamelinck and Hoogwijk 2007);
- Smeets 2008: 215 – 1272 EJ on surplus agricultural land, depending on advancements in agricultural technology (Smeets 2008).

The total gasoline and diesel consumption in the EU25 in 2010 was estimated to amount 13.7 EJ (Van den Broek et al 2003). In the European Union, diesel consumption is expected to increase to 180 Mtoe and gasoline consumption to decrease slightly to 100 Mtoe in 2020 (Harts 2001), the total of which equals about 12 EJ.

The above shows that the ambitions for 10% biofuels are rather modest in the light of the total biomass feedstock potential.

Table 3-1: Agricultural land available in different world regions (Olivier 2006) and maximal yield of energy from these acreages in 2050.

Region	**Total area (million km^2, or 100 Mha)**	**Total energy yield (EJ)**	
North America	573	9.5	(Methanol from wood)
Latin America	1282	24.8	(Ethanol from sugar cane)
Africa	1165	18.2	(Methanol from wood)
Europe	251	4.1	(Methanol from wood)
former USSR	1156	17.6	(Methanol from wood)
Asia (incl M.E.)	607	12.4	(Methanol from wood)
Oceania (incl NZL, JPN)	317	5.4	(Methanol from wood)
World	**5350**	**92.1**	

Yield

The yield of the various feedstock and processes varies a lot. This is due to several factors, including agricultural practices, feedstock type, conversion process and by products.

In Figure 3-3 an overview is given of the production per area for several biofuel chains. For each of the biofuel chains its gross and net energy yields per hectare are shown. The difference between gross and net energy yield is the amount of fossil energy required to fuel the chain. Also when the chain produces co-products, part of the land use can economically be allocated to these co-products. This is taken into account for the columns ‘with allocation’ but left out for the columns ‘without allocation’.

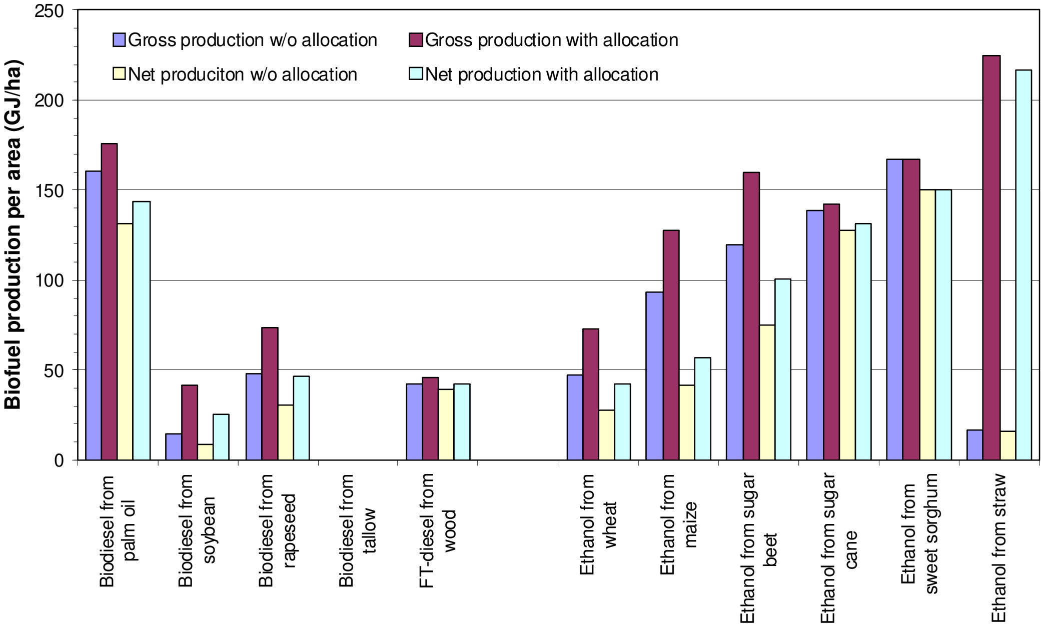

Figure 3-3: Overview of biofuel production per area per year for selection of chains (Ecofys 2006)

As can be seen from Figure 3-3, for some crops the allocation of land to by-products has a large effect on the yield of some chains. The concept of allocation is best demonstrated with an example. If ethanol is produced from wheat straw, the principle yield per hectare is very low. However not straw but wheat is the main product. We could state that the larger part of the field is dedicated to produce wheat. In the case of ethanol from wheat straw the impact of allocation is very large. Wheat is the main products and thus a large part of the land use is allocated to the wheat production instead of to the straw production. Further the actual yield of straw per hectare is relatively low. Biodiesel from soybean is also a chain where allocation has a large influence on the yield. It shows that the main product in this case (soy meal) has a larger economic value and thus a larger part of the land use is contributed to the main product.

On the contrary for ethanol from sugar cane, FT diesel from wood and biodiesel from palm oil the effects of allocation are very low. In case of sugar cane and palm oil, there are not so many or valuable agricultural by-products which influence the land allocation and thus the yield of the chain. The case of FT-diesel from wood is slightly different but might results from low regional yields of wood production in several countries.

Food versus fuel

Use of crops for energy in stead of food purposes is mainly a competition for suitable agricultural land. The degree of competition depends on the demand for both types of product (food and fuel) and the availability of suitable land to grow crops on. On the long term, regarding a global market, the competition between food and fuel can be balanced by increasing the yield per hectare of the crops.
Another aspect what might strongly reduce the competition between food and fuel on the long term, is the use of lignocellulose (woody) biomass for the production of fuels. These lignocellulose crops are no food crops and can be grown on other land, which might be less suitable for agriculture and food crops.

On the short term the use of crops for fuel production instead of food production, could also have some price effects. This is due to the response time of crops. Some crops used for the production of vegetable oils, have a short response time (one year) while other crops have a longer response time (up to several years). Especially increases in demand of crops with a longer response time can have prise raising effects on vegetable oil prices. This because additional production of vegetable oil, even if plantations are set up immediately, will only be available on the market after several years. In the years intermediate shortage might raise the price of the vegetable oil. This effect might be less for annual crops, where additional production of vegetable oils can be realised within 1 to 2 years.

On the long term, the prices of both food and fuel crops may actually decrease, if the increased demand is followed by efficiency improvements in worldwide agricultural technologies and increased yields.

A less tangible aspect in the food versus fuel discussion is the presence of the media and the opinions expressed in the media. General opinion and society might favour a certain type of feedstock over the other based on information spread by the media. This public opinion might be a reason for biofuel producers to change to other types of feedstock or stop using specific types of feedstock, to prevent a negative image towards the public. The discussion on food versus fuel as stated by the media and the extent in to which governments deal with these concerns could therefore influence the spectrum of biofuels on the short term.

Costs

The following graph depicts the costs for the production of various biofuels (2005). The stacked columns indicate which part of the total costs was caused by which step of the production process.

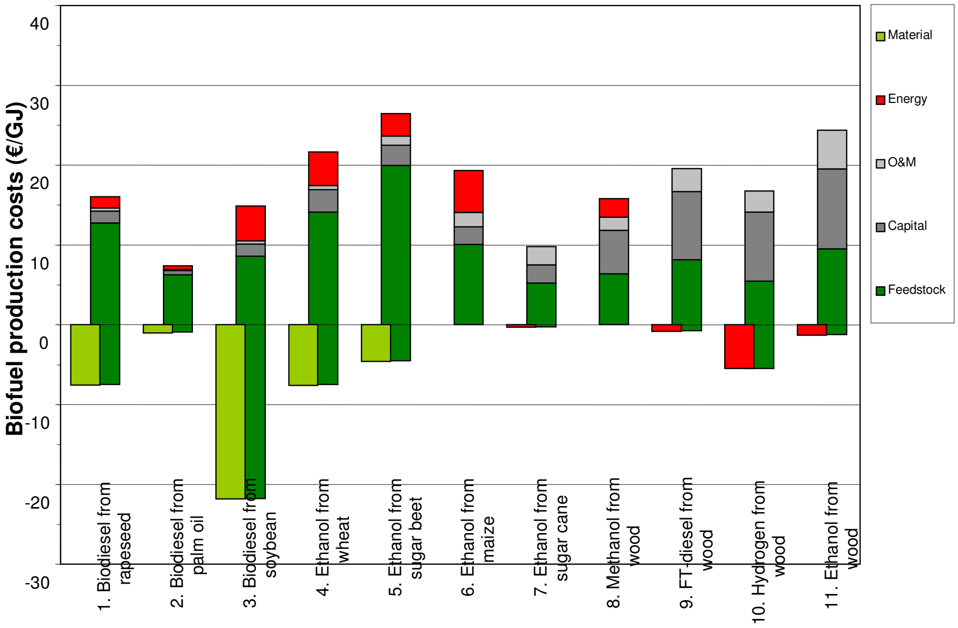

Figure 3-4. Overview of production costs of various biofuels in 2005 (Hamelinck and Hoogwijk 2007).

For most of the biofuels, the main part of the production costs is caused by the feedstock production. For some, like soybean, rapeseed, wheat and sugar beet, agricultural by-products create revenues which are shown by a downward column.
In most of the technologies in development (biofuels from wood) the contribution of capital investments are relatively high.

In Figure 3-5, the estimated costs for the same biofuel chains are shown for 2050.

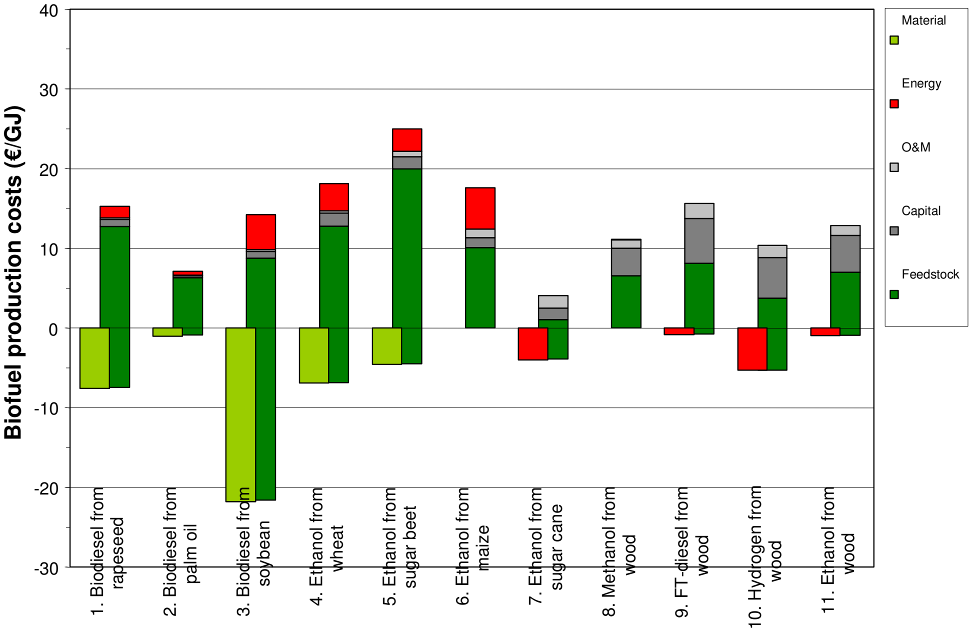

Figure 3-5. Overview of production costs of various biofuels in 2050 (Hamelinck and Hoogwijk 2007).

The main changes are expected in the biofuel chains using woody biomass as feedstock. Here capital investments are expected to be considerably lower in 2050, due to technological development.

GHG savings

Biofuels are used mainly because they bring about a reduction in greenhouse gas emissions compared to the use of conventional or fossil fuels.

In Figure 3-6, the reduction of emissions of a range of biofuels as compared to gasoline and diesel is shown. For the most common replacements of diesel GHG savings as compared to the diesel chain are depicted, while for the most common replacements of gasoline, the GHG savings are compared to the gasoline chain.

The graph shows that amongst the different biofuel chains there is a lot of variety in greenhouse gas emissions. The chain of ethanol from sugar shows the lowest emission, only 10% of the emissions of fossil fuels. The chains regarding biofuels from wood (second generation fuels) are all also very positive compared to the fossil chains (ranging between 20-30%).

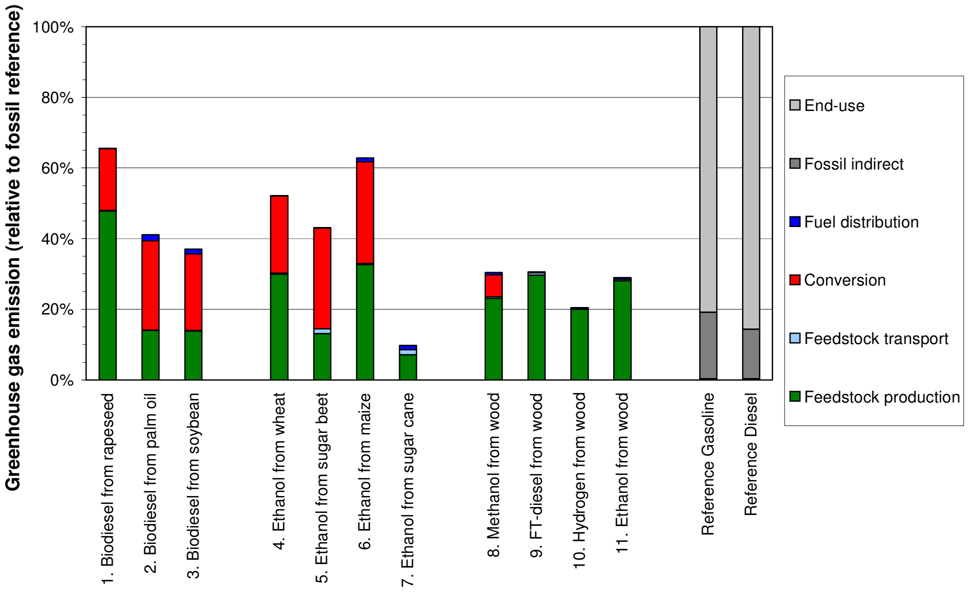

Figure 3-6. Greenhouse gas emissions as a result of delivering (bio)fuel to the end-user. The fossil references diesel and gasoline are normalised to 100 % (Hamelinck and Hoogwijk 2007)

Biodiesel from rapeseed and ethanol from maize can be regarded as the lesser positive chains, indicating a lower reduction of emissions (only about 40%).

In these chains, the possible effects of land use change are not taken into effect. This might result in occasionally higher greenhouse gas emissions if other lands than grasslands or current plantations are converted to feedstock plantations.

Greenhouse gas emission reduction is becoming increasingly important. It is probable that the European commission or the Dutch government will steer on greenhouse gas reduction percentages in the application of their biofuel targets. On average biofuel chains reduce the GHG emissions with 50%. A 10% reduction of GHG emissions will thus indicate a necessity of 20% market share of biofuels.

Further chains where further reduction of GHG emissions can be obtained relatively ‘simple’ will be favoured in their application.

Currently the European Commission is working on a Renewable Energy Directive (of which the Draft was published at 23.01.2008, Brussels) in which default values for GHG emissions are stated.

The figure below (Figure 3-7) displays the default values as stated in the current version of the RE directive. In some cases they vary slightly from the detailed calculations done by Hamelinck and Hoogwijk (2007).

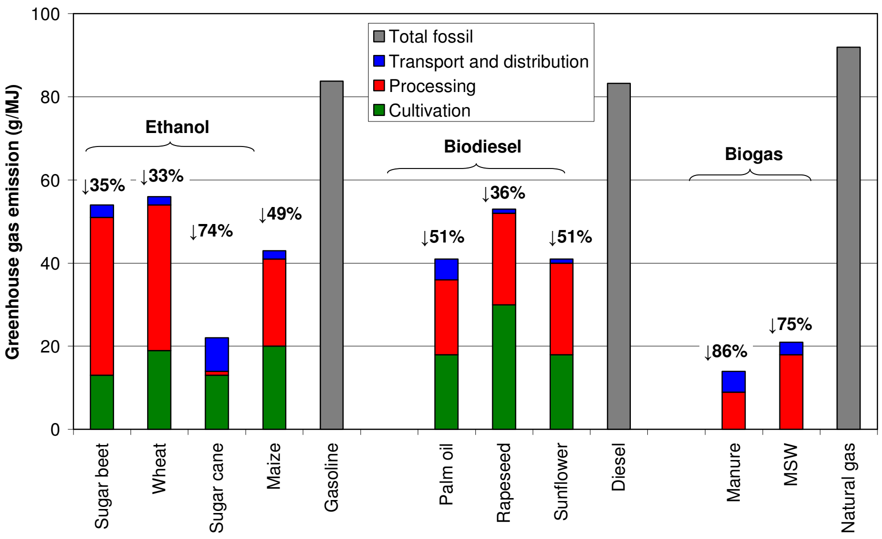

Figure 3-7 GHG emissions as set in the draft version of the RE Directive (January 2008)

Energy use

In all biofuel chains energy is used for the production of the biofuel. Figure 3-8 gives an overview of the energy use in several biofuel chains. In this graph, the biodiesel and FT-diesel chains are given relative to the reference diesel, while the ethanol chains are given relative to gasoline.

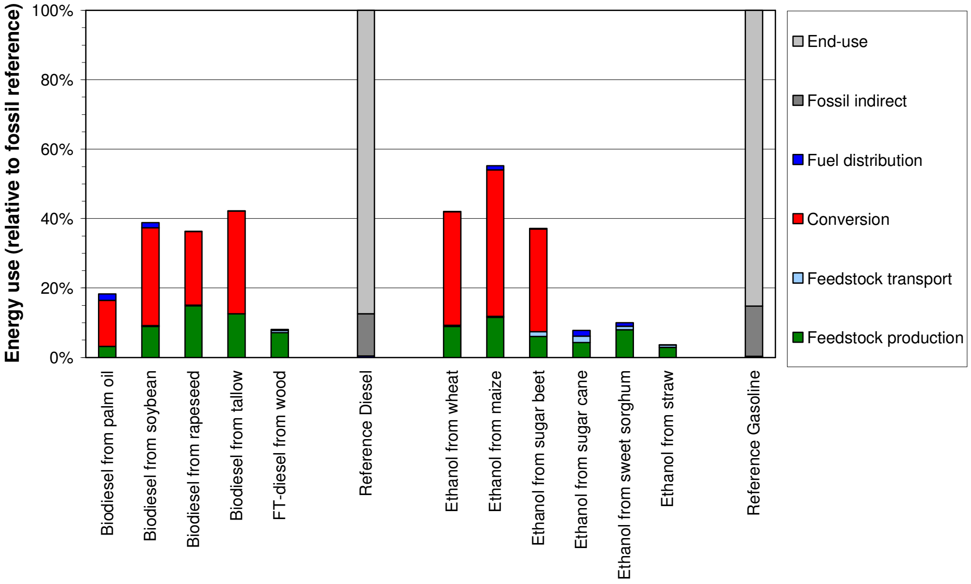

Figure 3-8. Energy use for various biofuel chains (Hamelinck et al 2006)

The chains which have a very low energy use (ethanol from straw, sugar cane and FT diesel from wood) all have low energy use in the conversion phase. In the other chains, the energy use during the conversion phase is the largest contribution to the total energy use.

Most of the fossil energy use in the feedstock phase is related to the use of machinery and the production of fertilizer (specifically nitrogen fertilizer).

3.2 Summary

The following tables summaries the main indicators for the different biofuels. ++ is given as very positive, -- as very negative compared to each other.

	Production costs	**Energy demand**	**Commercial Availability in 2020**	**GHG savings**	**Yield/land use**
Biodiesel/PPO Palm oil	++		++	+	++
Biodiesel/PPO Rapeseed	+	-	++	-	–
Biodiesel/PPO Soy	++	-	++	+	-
FT-Diesel	+/-	++	-	++	+/-
DME	+/-		-	++	+
Hydrogen fuel cells	+/-		-	++	

Gasoline replacers:

	Production costs	Energy demand	Commercially available	GHG savings	Yield/land use
Ethanol wheat	+/-		++	+/-	-
Ethanol sugar beet	+/-	-	++	+	+
Ethanol maize	+/-	-	++	-	
Ethanol sugar cane	++	++	++	++	
Cellulose ethanol wood	+/-		-	+	+

Stationary applications for electricity or heat

	Production costs	Energy demand	Commercially available	GHG savings	Yield/land use
Palm oil	+/-		++	+	
Wood	+		++	+	

3.3 Conclusions biofuel spectrum 2020

From the tables provided in Section 3.2 it can be concluded that a number of biofuel chains will probably have a significantly larger share in the biofuel spectrum in 2020 than the rest. This does not only depend on feedstock costs, availability or GHG savings but also for a large part on policy, subsidy schemes and sustainability regulation.

The impact of the biofuel chains based on lignocellulose material in 2020 might still be low due to the fact that most are not commercially available yet. Their influence on the longer term will be larger due to positive effects on GHG emission reduction, production costs and availability of biomass.

Therefore only currently commercially available biofuel chains are selected:

- <u>Diesel:</u>
  - Biodiesel from palm oil
  - Biodiesel from rapeseed
- <u>Gasoline:</u>
  - Ethanol from sugar cane
  - Ethanol from sugar beet
- <u>Stationary application for electricity/heat:</u>
  - Palm oil
  - Wood

4 Well to tank emissions

To determine the emissions resulting from the selected biofuel chains, the chains were modelled with the help of the software Simapro. In this manner a life cycle inventory could be performed and the well to tank emissions effecting local air quality determined. These emissions can be used to determine the impact on air quality for 2020 estimated.

4.1 Methodology and modelling

In this chapter the results from the Simapro modelling are given per chain. The chains are modelled using state of the art technology including technical improvements based on current knowledge. Most chains are modelled according to current best available technological practice (state of the art technology) and technical improvements are taken into account where foreseen based on current knowledge.

The exact data used for the modelling of the chains is given in Appendix A, which is mostly based on the literature and expertise meetings used for the development of the Greenhouse Gas Calculator (Ecofys 2007, CML 2007).

Simapro uses, among others, the Ecoinvent database, which is a non aggregated database. All subprocesses linked to the modelled process are taken into account in the calculations.

As an example Figure 4-1 displays the results provided by Simapro, where only 16 of the nearly 1600 subprocess are shown (a cut off percentage of 3% is used, which indicates that these are the subprocesses which contribute for more than 3% to the total). This example concerns the phase feedstock production in the biodiesel from rapeseed chain and displays only the results concerning nitrogen oxides. To prevent confusion and to reduce the detail level of the information provided in this report, in the following sections aggregated results in the form of overview tables are given for the various phases in the biofuel production chains.

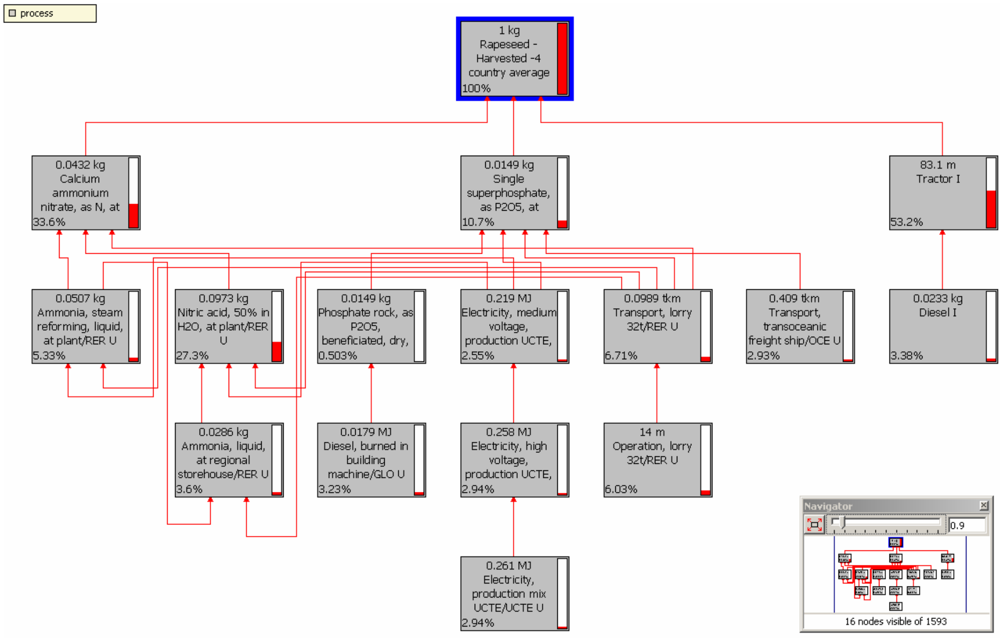

Figure 4-1: Example output feedstock production phase in biodiesel from rapeseed production chain for Nitrogen oxides emissions.

Reliability

In this project an attempt is made to display an average situation for the production processes of the biofuel chains selected. In reality there will always exist better or worse processes. Through examining this average situation, the general effect of biofuel policy on emissions to air quality can be given.

The reliability of the detailed calculations in Simapro, are for the larger part determined by two aspects:

- The reliability/variation of the input parameters;
- The uncertainty surrounding technological innovation and development.

The input parameters have an influence on the reliability of the outcomes. However input parameters will mostly vary within a range. The values used for the various input parameters within these calculations are mostly based on the preferred literature and expert opinions as expressed within the development of the Greenhouse Gas Calculator for the Dutch government (CML 2007, Hamelinck et al 2008).

The uncertainty around technological development is a lot larger and more difficult to predict. Technological development can also be steered/pushed by policy or market.

4.2 Relevant emissions for selected chains

In the following tables (Table 4-1 until Table 4-6) the results for each of the chain on the components NOx, SOx, NH3, NMVOS, PM10 and PM2.5 are shown. First a general description of the similarities for all the emissions is given. Then specific comments or deviations per chain are analyzed.

Finally an overview of all emissions per chain is given and chains are shortly compared.

General remarks air quality emissions biofuel chains

Some general remarks are given first to avoid repetition in describing each of the chains. This due to the fact that many of the emissions result from similar sources in each of the chains. The various process steps will be briefly described to give the overall similarities.

Feedstock production:

The larger part of the **NOx** emissions during feedstock production are the result of the use of a tractor. Further emissions result from the use and production of N fertilizer (nitric acid used in its production). Sometimes smaller contributions are made by K and P fertilizer (mainly the diesel use in production) if these are applied in large quantities.

SOx emissions in feedstock production mainly result from production of P fertilizer (use of sulphuric acid in this process). In some process sulphur dioxides are emitted through diesel use. Some small contributions could result from large applications of N and K fertilizer (diesel use in the production of these fertilizers).

NH3 emissions are the result of the use of nitric acid in the production of N fertilizer. Some small contributions are possible from the harvesting process.

The use and production of limestone in N fertilizer result in the high amounts of **PM10** emissions during feedstock production. **PM2.5** emissions result from the use of ammonia, nitric acid and limestone in the production of N fertilizer.

Feedstock transport:

NOx emissions result from the direct use and operation of the truck used to transport feedstock. Small contributions to emissions can be made if a ship is used for transport but main emissions result from the truck.

Large emissions regarding **SOx** and **NH3** are present when a sea ship is used for transport feedstock, further smaller amounts of emission result from use of truck, underlying infrastructure for road transport and diesel production for use in truck.

PM10 emissions result from the use of the truck in transport of feedstock, whereas **PM2.5** emissions are only present if a sea ship is used for part of the feedstock transport. NMVOC emissions are mainly caused by the production of N fertilizer and small contributions from K fertilizer.

Conversion process:

For biodiesel processes methanol production and use, and to a lesser extent the use of sodium hydroxide, results in emissions of **NOx, SOx** and **NH3**. For ethanol processes, production of natural gas results in the emissions for **NOx, SOx** and **NH3**. For the heat/electricity chains main causes of emissions in conversion are electricity or natural gas use. Electricity generation based on coal is an important contributor.

PM10 and **PM2.5** emissions, if present, are mainly the results of the use of limestone, electricity (based on coal) or natural gas in methanol production.

Fuel distribution:

For **NOx** emissions the main reason is the direct use of the truck in fuel distribution. For **SOx**, **NH3** and **PM10** emissions resulting from secondary processes (infrastructure, underlying fuel structure and fuel use) are larger than those resulting from direct operation of the truck. **PM2.5** only gives emissions when a ship is used for fuel distribution.

Expected improvements

The tractor and the fertilizer production appear to be the main contributors to emissions effecting air quality in the depicted biofuel chains.

Regarding tractors used for feedstock production within Europe, the emissions of nitrogen dioxides might be reduced due to current policy measures by the European commission resulting in lowering maximum allowed NO_x emissions. At the moment tractors are still behind regarding emission restrictions compared to other transport possibilities.

For sulphur there are currently no set new regulations but current negotiations might results in policy which will reduce sulphur measures quite drastically so that sulphur emissions might even be negligible. The used emission factors for tractor are given in Annex B.

Regarding fertilizer production there are currently several new developments which should cause a reduction of the laughing gas emissions at the production facilities. However this will have no effect on emissions with respect to air quality. Therefore it is not expected that these emissions will reduce in the coming years. Possible differences due to geographical location for fertilizer plants are not taken into account.

Thus the main improvements to be expected towards 2020 will be in the transport sector, mainly regarding emissions of tractors. This can mainly be expected from chains which occur mostly within the EU.

Specific remarks chains

The following tables give the results regarding emissions from the modelling of the whole biofuel chain expect end use in Simapro. In each table emission for NOx, SOx, NH3, PM10 and PM2.5 are given. Further the total result for NMVOC are given, with separately indicating the contributions of Benzene, Ethene, Styrene and Toluene.

Table 4-1. Results from emissions analysis of biodiesel from rapeseed chain excluding end use as modelled in Simapro (g per tonne of biodiesel)

	Unit	**Feedstock production**	**Feedstock transport**	**Conversion process**	**Fuel distribution**	**Total**
NOx	g	3.5E+03	3.5E+02	3.7E+02	1.0E+02	4.3E+03
SO2	g	1.6E+03	86	3.2E+02	25	2.0E+03
NH3	g	2.2E+03	0.03	1	0.01	2.2E+03
PM10	g	6.4E+02	23	16	7	6.9E+02
PM2.5	g	2.0E+02	0.00	12	0.00	2.1E+02
NMVOS total	g	1.6E+02	9	1	3	1.7E+02
Benzene	g	2	0.43	0.69	0.12	3
Ethene	g	0.22	8	0.11	2	11
Styrene	g	0.00	0.00	0.00	0.00	0.00
Toluene	g	1	0.13	0.34	0.04	2

Table 4-2. Results from emissions analysis of biodiesel from palm oil chain excluding end use as modelled in Simapro (g per tonne of biodiesel)

	Unit	**Feedstock production**	**Feedstock transport**	**Conversion process**	**Fuel distribution**	**Total**
NOx	g	1.4E+03	2.3E+02	3.3E+02	1.0E+02	2.1E+03
SO2	g	9.8E+02	1.1E+02	2.0E+02	24.69	1.3E+03
NH3	g	8.7E+02	0.54	1	0.01	8.7E+02
PM10	g	2.0E+02	15	12	7	2.3E+02
PM2.5	g	72	2.21	9	0.00	82
NMVOS total	g	71	5	0.97	3	80
Benzene	g	0.73	0.28	0.56	0.12	2
Ethene	g	0.10	5	0.12	2	7
Styrene	g	0.00	0.00	0.00	0.00	0.00
Toluene	g	0.43	0.09	0.29	0.04	0.85

Table 4-3. Results from emissions analysis of ethanol from sugar cane chain excluding end use as modelled in Simapro (g per tonne of ethanol)

	Unit	**Feedstock production**	**Feedstock transport**	**Conversion process**	**Fuel distribution**	**Total**
NOx	g	9.3E+02	2.1E+03	28.84	22	3.1E+03
SO2	g	2.0E+02	5.1E+02	1.1E+02	6	8.2E+02
NH3	g	98	0.18	0.03	0.10	98
PM10	g	86	1.4E+02	0.00	0.41	2.2E+02
PM2.5	g	24	0.00	0.00	1	25
NMVOS total	g	62	54	0.09	0.06	1.2E+02
Benzene	g	0.25	3	0.02	0.04	3
Ethene	g	0.03	50	0.05	0.00	50
Styrene	g	0.00	0.00	0.00	0.00	0.00
Toluene	g	0.14	0.76	0.02	0.02	0.94

Table 4-4. Results from emissions analysis of ethanol from sugar beet chain excluding end use as modelled in Simapro (g per tonne of ethanol)

	Unit	**Feedstock production**	**Feedstock transport**	**Conversion process**	**Fuel distribution**	**Total**
NOx	g	1.3E+03	2.2E+03	5.2E+02	1.0E+02	4.1E+03
SO2	g	5.3E+02	5.5E+02	3.4E+02	24.69	1.4E+03
NH3	g	1.5E+02	0.19	0.35	0.01	1.5E+02
PM10	g	1.5E+02	1.5E+02	7	7	3.1E+02
PM2.5	g	51	0.00	8	0.00	58
NMVOS total	g	74	58	0.48	3	1.3E+02
Benzene	g	0.56	3	0.24	0.12	4
Ethene	g	0.06	54	0.08	2	57
Styrene	g	0.00	0.00	0.00	0.00	0.00
Toluene	g	0.30	0.81	0.15	0.04	1

Table 4-5. Results from emissions analysis of woodpellets chain excluding end use as modelled in Simapro (g per tonne of woodpellets)

	Unit	**Feedstock transport**	**wood pellets**	**pellets transport**	**Total**
NOx	g	1.2E+02	2.6E+02	80	4.6E+02
SO2	g	46	2.9E+02	2.0E+02	5.4E+02
NH3	g	0.47	3	0.80	4
PM10	g	4	15	5	25
PM2.5	g	7	36	4	47
NMVOS total	g	67	0.70	0.15	68
Benzene	g	0.22	0.53	0.09	0.84
Ethene	g	0.01	0.02	0.01	0.04
Styrene	g	0.00	0.00	0.00	0.00
Toluene	g	0.12	0.15	0.05	0.32

Table 4-6. Results from emissions analysis of crude palm oil chain excluding end use as modelled in Simapro (g per tonne of CPO)

	Unit	**Feedstock production**	**Feedstock transport**	**Conversion process**	**Fuel distribution**	**Total**
NOx	g	1.3E+03	2.3E+02	1.8E+02	22.76	1.8E+03
SO2	g	9.3E+02	1.1E+02	1.1E+02	8	1.2E+03
NH3	g	8.3E+02	0.54	0.11	0.12	8.3E+02
PM10	g	1.9E+02	15	1	0.49	2.1E+02
PM2.5	g	68	2	0.00	1	71
NMVOS total	g	68	5	0.35	0.06	73
Benzene	g	0.70	0.28	0.14	0.04	1
Ethene	g	0.09	5	0.12	0.00	5
Styrene	g	0.00	0.00	0.00	0.00	0.00
Toluene	g	0.41	0.09	0.10	0.02	0.62

Some patterns and irregularities can be identified from the tables above:

- the NOx, SOx and PM10 emissions resulting from feedstock transport in the sugar beet and sugar cane chain are a higher or of the same range as the emissions in feedstock production. This is different than to the other chains where emissions in the feedstock production phase are two to three times larger than the feedstock transport emissions. The main difference here might result from the fact that sugar beet and sugar cane have a high moisture content, therefore a lot of feedstock need to be transported to obtain one litre of ethanol;
- Emissions from the rapeseed chain are a lot higher than the other chains, but mainly due to its large emissions in the feedstock production phase. This is mainly the result of a high use of N fertilizer per kg of biodiesel;

- PM2.5 emissions in the fuel distribution phase are only present when a ship is used[1]. PM10 emissions are also resulting from the use of truck transport;
- NH3 emissions almost solely occur during feedstock production and not in the other phases. The use of nitric acid in the production of N fertilizer is the main cause for these emissions.
- NMVOC emissions for biodiesel from palm oil and CPO in the feedstock production are high, mainly caused by high emissions of benzene and toluene (caused by the production of N fertilizer). For biodiesel from rapeseed and ethanol from sugar cane emissions are relatively low and contribution from benzene, ethane, styrene and toluene are almost nihil. For ethanol from sugar beet and wood pellets, the emissions of NMVOC are relatively low but mainly caused by benzene or toluene emissions (for sugar beet caused by fertilizer production, for wood pellets by the energy used to produce pellets).

Total emissions per chain

In the following tables (Table 4-7 until Table 4-10) an overview is given of the total emissions in g/tonne end product are given for the compounds NOx, SOx, NH3, NMVOS, PM10 and PM2.5.

Each product type is compared to an equivalent amount of fossil reference. For the biodiesel chains, conventional diesel is taken (equivalent amount of 0.88 tonne diesel). For the ethanol chains, gasoline is used (equivalent amount of 0.61 tonne of gasoline). For crude palm oil, natural gas is used a reference (1.0 tonne of natural gas) and for wood pellets, coal is used as reference (0.61 tonne coal). The equivalent amount is calculated assuming similar end use efficiencies per product type, using the lower heating values of the different fuels.
Short conclusions on the comparison with the reference are given below the tables.

Table 4-7 Overview of total emissions per chain for biodiesel and an equivalent amount of conventional diesel as reference

		Biodiesel from rapeseed	**Biodiesel from palm oil**	**Diesel Ref**
Nox	**g/tonne**	4.3E+03	2.1E+03	1.7E+03
SO2	**g/tonne**	2.0E+03	1.3E+03	3.6E+03
NH3	**g/tonne**	2.2E+03	8.7E+02	5
PM10	**g/tonne**	6.9E+02	2.3E+02	88
PM2.5	**g/tonne**	2.1E+02	82	1.6E+02
NMVOS	**g/tonne**	1.7E+02	80	89
Benzene	**g/tonne**	3	2	6
Ethene	**g/tonne**	11	7	5
Styrene	**g/tonne**	0.00	0.00	0.00
Toluene	**g/tonne**	2	0.85	8

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[1] Simapro does not give any PM2.5 emissions resulting from the use of a truck. We assume this is not correct but that the PM2.5 emissions have not been taken into account when modelling the subprocess. This might be an interesting point for further investigation.

Regarding the compounds NOx, NH3, PM10 and ethene the conventional reference has lower emissions than both biofuel chains. For SOx, benzene and toluene the biofuel chains have lower emissions. Further biodiesel from palm oil has lower emissions for PM2.5 and NMVOS than the fossil reference, while biodiesel from rapeseed has higher emissions than the fossil reference here.

Comparing biodiesel from palm oil with biodiesel from rapeseed, the rapeseed chain is the one with the highest emissions for all compounds. Biodiesel from palm oil has emissions of up to 50% lower than those of the rapeseed chain (for all compounds).

Overall the biofuel chains mainly have a larger negative effect on NOx emissions and PM10 emissions than their fossil reference while SOx emissions are more positive than the fossil reference.

Table 4-8 Overview of total emissions per chain for ethanol and an equivalent amount of conventional gasoline as reference

		Ethanol from sugar cane	**Ethanol from sugar beet**	**Gasoline Ref**
NOx	**g/tonne**	3.1E+03	4.1E+03	1.4E+03
SO2	**g/tonne**	8.2E+02	1.4E+03	3.5E+03
NH3	**g/tonne**	98	1.5E+02	4
PM10	**g/tonne**	2.2E+02	3.1E+02	74
PM2.5	**g/tonne**	25	58	1.4E+02
NMVOS	**g/tonne**	1.2E+02	1.3E+02	76
Benzene	**g/tonne**	3	4	5
Ethene	**g/tonne**	50	57	3
Styrene	**g/tonne**	0.00	0.00	0.00
Toluene	**g/tonne**	0.94	1	6

The biofuel chains (ethanol from sugar cane and from sugar beet) have higher emissions with respect to local air quality than their fossil reference (gasoline) regarding the emissions on NOx, NH3, PM10, NMVOS and ethane. Regarding emissions of SOx, PM2.5, benzene and toluene the emissions of the fossil reference (gasoline) are higher than the biofuel chains.

Comparing the two biofuel chains, the emissions associated with the production of ethanol from sugar beet are for all compounds higher than those of ethanol from sugar cane. The difference in emissions is not as large for all compounds (for some compounds the emissions are quite similar while for other compounds the emissions for sugar cane are about 50% lower).

Overall biofuels have a large negative effect on emissions of NOx, and PM10 compared to the fossil reference, but a large positive effect on SOx.

Table 4-9. Overview of total emissions per chain for crude palm oil and an equivalent amount of natural gas as reference

		CPO	**Natural Gas Ref**
Nox	**g/tonne**	1.8E+03	8.8E+02
SO2	**g/tonne**	1.2E+03	9.9E+02
NH3	**g/tonne**	8.3E+02	0.83
PM10	**g/tonne**	2.1E+02	38
PM2.5	**g/tonne**	71	39
NMVOS	**g/tonne**	73	0.22
Benzene	**g/tonne**	1	0.14
Ethene	**g/tonne**	5	0.00
Styrene	**g/tonne**	0.00	0.00
Toluene	**g/tonne**	0.62	0.06

Regarding all emissions, the chain for crude palm oil has higher emissions than its fossil reference, namely natural gas used for heat or electricity production.

For most of the compounds, NOx, NH3, PM10, PM2.5 and NMVOS, the difference is substantial. For the others, namely SOx and benzene, the differences are a lot smaller.

Table 4-10. Overview of total emissions per chain for wood pellets and an equivalent amount of coal as reference

		Wood pellets	**Coal Ref**
Nox	**g/tonne**	4.6E+02	1.7E+03
SO2	**g/tonne**	5.4E+02	1.1E+03
NH3	**g/tonne**	4	79
PM10	**g/tonne**	25	69
PM2.5	**g/tonne**	47	63
NMVOS	**g/tonne**	68	68
Benzene	**g/tonne**	0.84	1
Ethene	**g/tonne**	0.04	0.00
Styrene	**g/tonne**	0.00	0.00
Toluene	**g/tonne**	0.32	0.00

Regarding most compounds the biofuel chain, wood pellets used for stationary applications, has lower emissions than the fossil reference (coal). The differences between the biofuel and fossil reference are substantial. Only for NMVOS and benzene the emissions are relatively the same, while for toluene the emissions from the biofuel chain are slightly higher. In this chain wood pellets are based on waste wood (from saw mills). Using wood especially produced for wood pellets will raise the emissions a little mainly because a larger part of the electricity and diesel used in the sawing and harvesting of the wood will be allocated to the pellets then.

To give a short indication of where main differences between the biofuel chains may lie the lower heating values of the different fuels are presented in Table 4-11. These can give a brief indication of comparison between the different chains, not taking into account type of end use and end use efficiency.

Table 4-11. LHV for the main end production of the biofuel chains (GJ/tonne) (Ecofys 2007)

	LHV (GJ/tonne)
Biodiesel	37.3
Ethanol	26.4
CPO	39.3
Wood (10% moisture)	16.8
Diesel (ref)	42.5
Gasoline (ref)	43.4
Natural gas (ref)	38.8
Coal (ref)	27.7

From Table 4-11 it can be concluded that the difference between lower heating value for biodiesel and ethanol is about 30%. The difference between biodiesel and CPO is small. Regarding wood pellets the LHV is about 30% of that of biodiesel and 45% of that of ethanol.

Table 4-7 to Table 4-10 show that the chain for biodiesel from rapeseed has the largest emissions, especially regarding SOx, NH3, PM10 and PM2.5 (main causes are in the feedstock production phase). Regarding NOx the emissions for ethanol from sugar beet are also very large (due to large contribution of feedstock transport). Taking into account the lower heating values, it can be concluded that the biodiesel from rapeseed, ethanol from sugar beet and to a lesser extent ethanol from sugar cane have the largest impact on air quality emissions.

The chain for wood pellets shows very low emissions, but lower heating value is also low. When placing these in perspective (3 times higher to compare with biodiesel emissions and 2.5 times higher to compare with ethanol emissions), the chain for wood pellets can still be regarded as very positive and with very little emissions effecting air quality as compared to the other chains. One of the main reasons for this is that the wood pellets chain is based on wood residues, so that feedstock production is not taken completely into account.

Greenhouse gas emissions

The relevance of greenhouse gas emissions was already indicated in section 3.1 where they were among other aspects used for the selection of the chains of importance in 2020. In Table 4-12 an overview of the greenhouse gas emissions as calculated by Hamelinck and Hoogwijk (2007) is given.

Table 4-12. Overview GHG emissions for the selected chains (Hamelinck en Hoogwijk 2007)[2]

	Unit	Feedstock production	Feedstock transport	Conversion process	Fuel distribution
Biodiesel from rapeseed	g/tonne	1.43E+06	5.92E+03	5.38E+05	2.95E+03
Biodiesel from palm oil	g/tonne	4.33E+05	1.28E+03	7.80E+05	5.20E+04
Ethanol from sugar cane	g/tonne	2.76E+05	3.05E+04	6.30E+05	2.78E+03
Ethanol from sugar beet	g/tonne	2.00E+05	4.05E+04	0.00E+00	3.99E+04

The reduction related to these GHG emissions as compared to their fossil reference (where end use is taken into account) is indicated in Table 4-13.

Table 4-13. Overview GHG emission reduction for the selected chains (Hamelinck en Hoogwijk, 2007)

	% reduction compared to fossil reference
Biodiesel from rapeseed	36%
Biodiesel from palm oil	59%
Ethanol from sugar cane	87%
Ethanol from sugar beet	57%
Crude palm oil[3]	75%
Wood pellets[4]	94%

The table shows that the highest reductions are obtained by the use of ethanol from sugar cane or biodiesel from palm oil.

4.3 Geographical impact of emissions

Main emissions result from the feedstock production. Regarding the chains, the feedstock production takes place in various locations. In this project the main divisions for geographical locations are Netherlands, Europe and outside Europe.

For several chains emissions could take place on various locations. Here the main production locations for each biofuel chain are assumed.

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[2] The chains electricity/heat from CPO or wood pellets are not calculated in Hamelinck and Hoogwijk 2007

[3] The reduction percentage for crude palm oil was deducted from the Greenhouse gas calculator (Ecofys 2007, biodiesel from palm oil chain) and compared to the direct emissions from the combustion of an equivalent amount of natural gas

[4] The reduction percentage for wood pellets was deducted from Simapro. The value was checked using Elsayed 2003 and the direct emission from the combustion of an equivalent amount of coal

Table 4-14. Overview geographical locations biofuel chains.

Product	Feedstock production	Conversion
Biodiesel from rapeseed	EU/Netherlands	EU/Netherlands
Biodiesel from palm oil	Outside EU (South east Asia, Africa)	Outside EU/partly inside EU[5]
Ethanol from sugar cane	Outside EU (Latin America)	Outside EU (Latin America)
Ethanol from sugar beet	Netherlands/EU	Netherlands/EU
Crude palm oil	Outside EU (South east Asia, Africa)	Outside EU (South east Asia, Africa)
Wood pellets	Outside EU (Canada and North America)/Inside EU (Scandinavia and Baltic States)	Outside EU (Canada and North America)/Inside EU (Scandinavia and Baltic States)

For the fossil chains, the geographical spread is indicated in the following table:

Table 4-15. Overview geographical locations fossil reference chains

Product	Production and refining[6]
Diesel	All within EU, outside NL
Gasoline	All within EU, outside NL
Natural gas	EU average mix, with 24% of the gas coming from NL
Coal	10% inside EU, rest outside EU (World). Nothing inside NL

Fuel distribution for the fossil chains all takes place in EU and partly in the Netherlands.

The chain with the largest impact on air quality emissions is the rapeseed chain. Most of the steps in this chain occur within Europe and even within the Netherlands. Chain with second largest emissions is sugar beet, of which most of the steps in the LCA also occur within the Netherlands or at least within Europe.

For the other chains (biodiesel from palm oil, ethanol from sugar cane, CPO for heat/electricity and wood pellets for heat/electricity) main emissions occur during feedstock production which takes place outside Europe. Only regarding wood pellets could emissions take place within Europe, but the size of emissions from this chain are a lot smaller than those of the other chains.

Quantifying the geographical impact of the emissions on air quality from the biofuel chains selected can be done in various way, some very elaborate some more focused.

A suggested approach might be the following, which could be deepened to the preferred level of detail in a possible second part of the project. The example used here, will be the chain of biodiesel from palm oil.

In the following figure (Figure 4-2) the geographical split for the biodiesel from palm oil chain as used in this example is shown.

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[5] This would only hold for the final conversion step of CPO into biodiesel. The first step from fresh fruit bunches into CPO will always take place in the land of feedstock production.

[6] Simapro does not make a detailed split between all steps in the production and refining of the fossil chains.

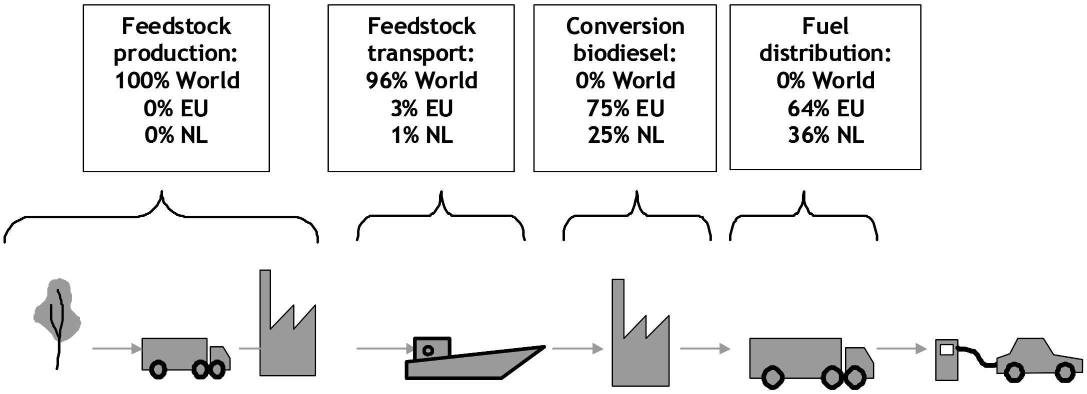

Figure 4-2 Overview of geographical split of biodiesel from palm oil chain

The percentages presented here are indicative and will require more thorough discussion and investigation. They are used here to indicate a possible approach to quantify emissions occurring within the Netherlands in the case of biodiesel from palm oil. They are based upon the following assumptions:

- **Feedstock production:** Production of palm oil takes place in other regions of the world like Malaysia and Indonesia
- **Feedstock transport:** Feedstock transport consists of a sea ship travelling from country of origin to Europe. The larger part of this journey takes place outside the EU (96%) and only at delivering to the conversion plant a part can be contributed to NL. As stated at the section conversion, one third of the biofuel is processed within the NL, the rest outside the NL but within the EU.
- **Conversion:** The basic assumption is that 25% of the palm oil is converted into biodiesel within the NL, the rest in other countries in Europe
- **Fuel distribution:** Transport distances for the 25% produced in the NL are completely attributed directly to NL and further a 15% of the transport distances for the biofuel produced on other locations in Europe, resulting in 36%.

The percentages given in Figure 4-2 can be multiplied by the results given in Table 4-2 resulting in the total emissions occurring within the Netherlands for the biodiesel from palm oil chain.

Table 4-16 Geographical impact of emissions on air quality within the Netherlands for 1 tonne biodiesel from palm oil, excluding end use

	Unit	Feedstock production	Feedstock transport	Conversion process	Fuel distribution	Total
NOx	g/tonne	0.00	2	83	36	122
SOx	g/tonne	0.00	1	51	9	61
NH3	g/tonne	0.00	0.01	0.26	0.00	0.27
PM10	g/tonne	0.00	0.15	3	2	5
PM2.5	g/tonne	0.00	0.02	2	0.00	2
NMVOS total	g/tonne	0.00	0.05	0.24	0.93	1
Benzene	g/tonne	0.00	0.00	0.14	0.04	0.19
Ethene	g/tonne	0.00	0.05	0.03	0.88	0.95
Styrene	g/tonne	0.00	0.00	0.00	0.00	0.00
Toluene	g/tonne	0.00	0.00	0.07	0.01	0.09
CO2	g/tonne	0.00	250.83	78185.09	3726.39	82162.31

The highest contribution of emissions on local air quality within the Netherlands will result from the conversion facilities for biodiesel based on palm oil, as displayed in Table 4-16.

The depicted approach could be elaborated to more detail by allocating percentages not to the overall process step (like feedstock production or conversion process) but to parts of these steps (like truck use, fertilizer production etc.).

4.4 Conclusions

Overall it can be concluded that the larger part of the emissions for most of the chains result from the feedstock production (in some cases even up to 50-75% of the total emissions). NOx emissions are in quantity the largest source of emissions. Main sources for NOx, SOx and NH3 emissions are the use of tractor, N fertilizer and chemicals during the conversion process,

Truck use mainly effects NOx and PM10 emissions while the use of ships causes more SOx, NH3 and PM2.5 emissions. Further large contributions for PM10 and PM2.5 are found in limestone use in fertilizer production.

PM10 and PM2.5 emissions result more from limestone use in N fertilizer and from the use of transport by truck or ship. NMVOC emissions mainly result from the production of N fertilizer.

After comparing with a fossil reference, it resulted that in general biofuel chains used for transport purposes have lower emissions regarding SOx, benzene and toluene while in general emission regarding NOx, NH3 and PM10 are higher.

Comparing biofuels for stationary applications with a fossil reference gives mixed results. Wood pellets comes out with overall lower emissions while CPO has overall higher emissions than its fossil references.

Furthermore it can be stated that the most negative effect on air quality will result from the biodiesel from rapeseed chain and ethanol from sugar beet chain. These final conclusions have been made roughly taking into account the lower heating values of the different biofuels because end use efficiency are not included in this study.

Most of these emissions from the most negative chains (biodiesel from rapeseed and ethanol from sugar beet) will take place within Europe or even within the Netherlands. An elaborate evaluation of the specific emissions within the Netherlands or within Europe should be performed to indicate the effect of the biofuel policy on local air quality within the Netherlands in 2020.

For the other chains, the largest emissions regarding air quality will take place in the country where feedstock production takes place, which is in most cases outside Europe.

Emissions during conversion and transport in general have a smaller impact on the total amount of emission. Exceptions in this case are the ethanol chains (sugar beet and sugar cane) which have a very high moisture content and therefore high emissions resulting from transport of feedstock. Again for the sugar beet chain, these emissions will completely take place within the Netherlands or else within Europe.

Improvements can be expected in the field of transportation, especially focussing on tractor end use emissions. Regulation for several emissions is planned within the EU. Therefore it can be stated that the chains occurring for the larger part within the EU will improve more caused by changes in legislation than the chains outside the EU.

5 Conclusions and recommendations

5.1 Conclusions

The following six biofuel chains were identified as those having a main contribution to the biofuel spectrum in 2020:

- Biodiesel from rapeseed;
- Biodiesel from palm oil;
- Ethanol from sugar cane;
- Ethanol from sugar beet;
- Heat/electricity from CPO;
- Heat/electricity from wood pellets.

These six chains were identified and selected after analyzing several factors among which development of the transport market, development of stationary applications, supply of feedstock, yield, costs, greenhouse gas savings and energy use.

Overall, it can be stated that the most negative risks for air quality reside in the supply chains for biodiesel from rapeseed chain and for ethanol from sugar beet. Ethanol from sugar cane could also lead to significant NO_x emissions. Wood pellets will have the least effect on air quality and might even reduce emissions to air in comparison to its fossil reference. End use and end use efficiency is not taken into these calculations. In most studies currently end use efficiency for biofuels is taken the same as its fossil reference, therefore the effect will be nihil.

Comparing the chains with a specific fossil reference gives differentiated results for transport and stationary applications. The biofuel chains used for transport purposes in general have lower emissions regarding SO_x, benzene and toluene while in general emission regarding NO_x, NH_3 and PM_{10} are higher than their fossil references.

The use of wood pellets for stationary applications results in overall lower emissions compared to its fossil references, coal. On the other hand CPO has overall higher emissions than its fossil reference, natural gas.

Regarding geographical location of emissions, it can be stated that largest amounts of emissions takes place during feedstock production. For the chains with most negative impact on air quality feedstock production occurs within Europe and even partly within the Netherlands. Production of these crops within the Netherlands will displace other agriculture. The net effect will then at least be import of other crops which are replaced[7].

It should be noted that changes in agricultural practice and policy could largely influence the results obtained from Simapro[8]. Especially agriculture within Europe (where most of the largest emissions take place) might be influenced to reduce these negative emissions (for example changes in practices on fertilizer use, production or tractor emissions). Changing practices on world scale are less expected within the next ten years.

Further GHG emissions are already used for steering practices in biofuel production. This will influence the air quality emissions when alternative practices are adopted (use of alternative ethanol conversion method because distillation uses a lot of energy and thus produces a lot of GHG emissions). This might have a positive effect on air quality emissions but in other cases might have a negative effect.

Furthermore effects on local air quality are currently not taken into account in steering biofuel production and use, therefore it is not clear whether improvements regarding GHG or agricultural practice will automatically have a positive impact on air quality.

Thus the most negative impact on air quality can be expected from rapeseed and sugar beet chains, within Europe or the Netherlands, with the comment that these are also the easiest chains to influence due to the location of feedstock production.

5.2 Recommendations

This orientating study resulted in the modelling of 6 biofuel chains, which are expected to have a large impact on the biofuel spectrum in 2020.

In the light of the variations found in feedstock and product type, it can be expected that much more biofuels supply chains play an important role in the biofuels spectrum of 2020. Further analyzing could also give an indication which chains might be favourable regarding air quality or which aspects of chains should be given attention regarding its impact on air quality.

Possibilities for the inclusion of other chains:

- Other currently commercial available biofuel chains;
- So called second generation chains, like ethanol from straw, ethanol from lignocellulose biomass (wood), or FT diesel based on biomass;
- Diesel or gasoline chain which could be used as reference.

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[7] This effect of displacing agriculture could be an interesting topic for further research

[8] Simapro is a modeling software which specializes in life cycle analysis. It is based on large and detailed databases, like the ECOINVENT database.

We furthermore suggest to detail the modelling to include or improve the following aspects:

- On those aspects which have a large impact on the outcomes or which seem to give relevant contributions to certain emissions;
- Those aspects which could be improved or changed due to technological change, agricultural improvements etc.
- Those aspects related to alternative energy provision by use of residues (for example by bagasse/palm kernel burning). Currently these are only taken into account on a relative simple manner;
- Those aspects which are relatively out dated in the Simapro database;
- To indicate more detailed the amount of emissions per chain which occur in the Netherlands.

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Annex A

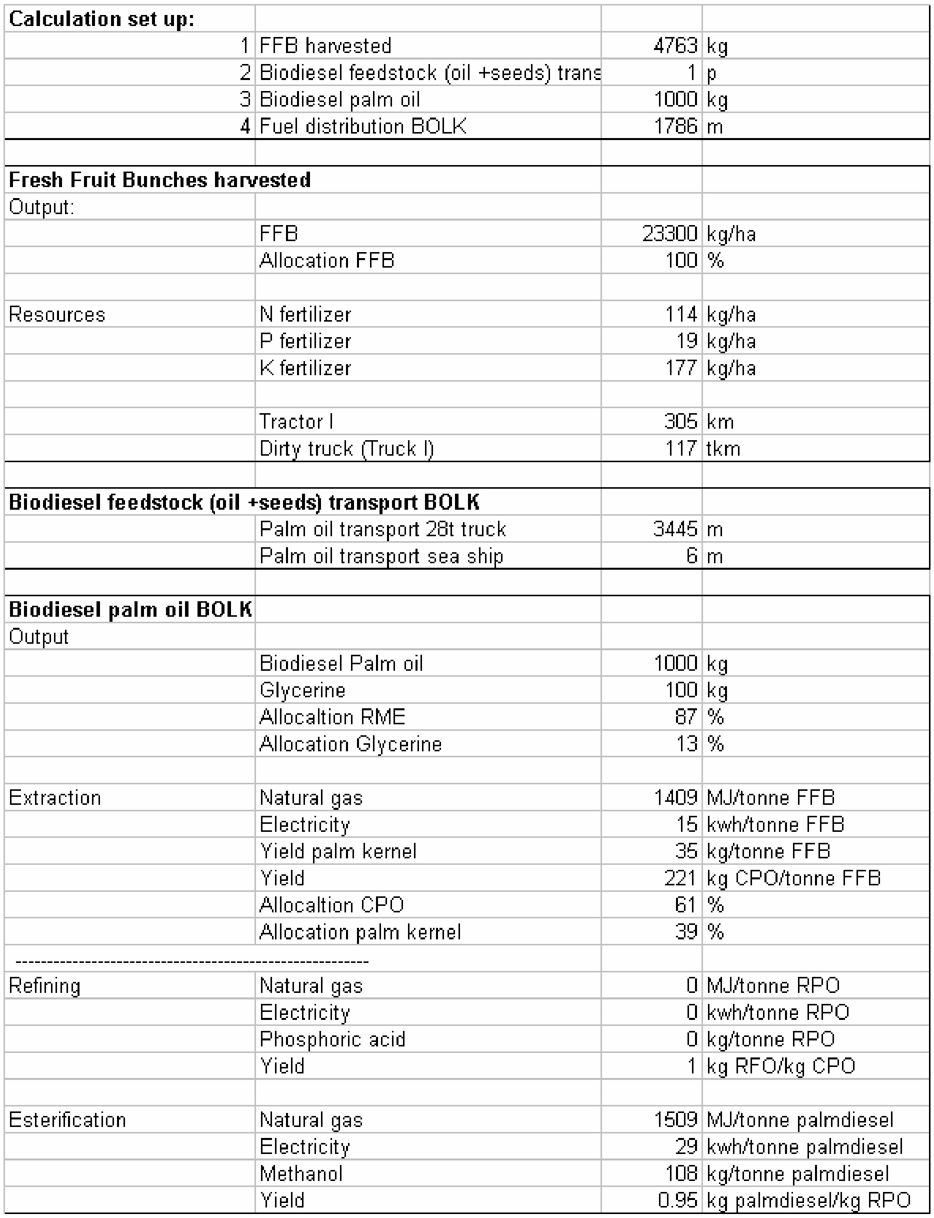
The data used for the modelling in Simapro was collected from the Technical Specifications as written for the GHG calculator for biofuels and electricity (Ecofys 2007, CML 2007). Best practice values were mainly used.

Data input as used for Simapro modelling per selected chain:

Biodiesel from rapeseed

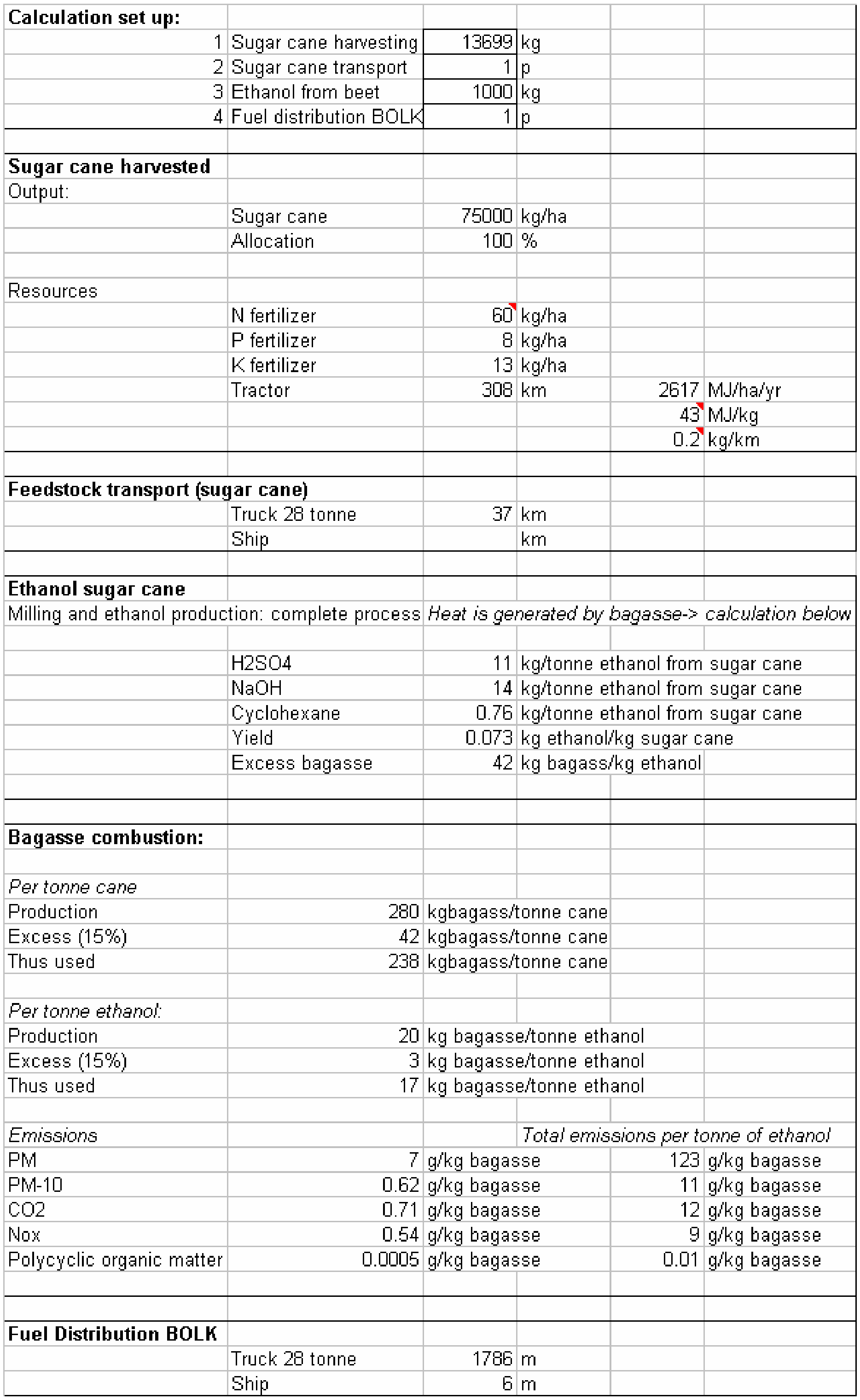
Calculation set up:			
1	Rapeseed harvested -4 country average	1736	kg
2	Biodiesel feedstock (oil +seeds) transpc	1	p
3	Biodiesel RME BOLK	1000	kg
4	Fuel distribution BOLK	1786	m
Rapeseed harvested -4 country average - BOLK			
Output:			
	Rapeseed harvested	3410	kg/ha
	Straw	2580	kg/ha
	Allocation rapeseed	91	%
	Allocation straw	9	%
Resources			
	N fertilizer	162	kg/ha
	P fertilizer	56	kg/ha
	K fertilizer	32	kg/ha
	Tractor	311	km
Biodiesel feedstock (oil +seeds) transport BOLK			
	Feedstock transport by 28 tonne truck	6199	m
	Feedstock oil transport by sea ship	8	m
	Feedstock oil transport by barge	137	m
Biodiesel RME BOLK			
Output:			
	Biodiesel RME	1000	kg
	Glycerine	100	kg
	Allocaltion RME	87	%
	Allocation Glycerine	13	%
Storage:			
	Electricity	11.6	kwh/tonne CRO
	Yield	0.94	kg dried rapeseed/raw rapeseed
Extraction	Natural gas	604	MJ/tonne raw rapeseed
	Electricity	32	kwh/tonne raw rapeseed
	Hexane	0.95	kg/tonne raw rapeseed
	Yield		
--			
Refining	Natural gas	345	MJ/tonne RME
	Electricity	3	kwh/tonne RME
	Phosphoric acid	1	kg/tonne RME
	Yield	1074	kg CRO/tonne RME
Esterification	Natural gas	1509	MJ/tonne RME
	Electricity	23	kwh/tonne RME
	Methanol	108	kg/tonne RME
	Yield	0.95	kg RME/kg refined RO

Biodiesel from palm oil



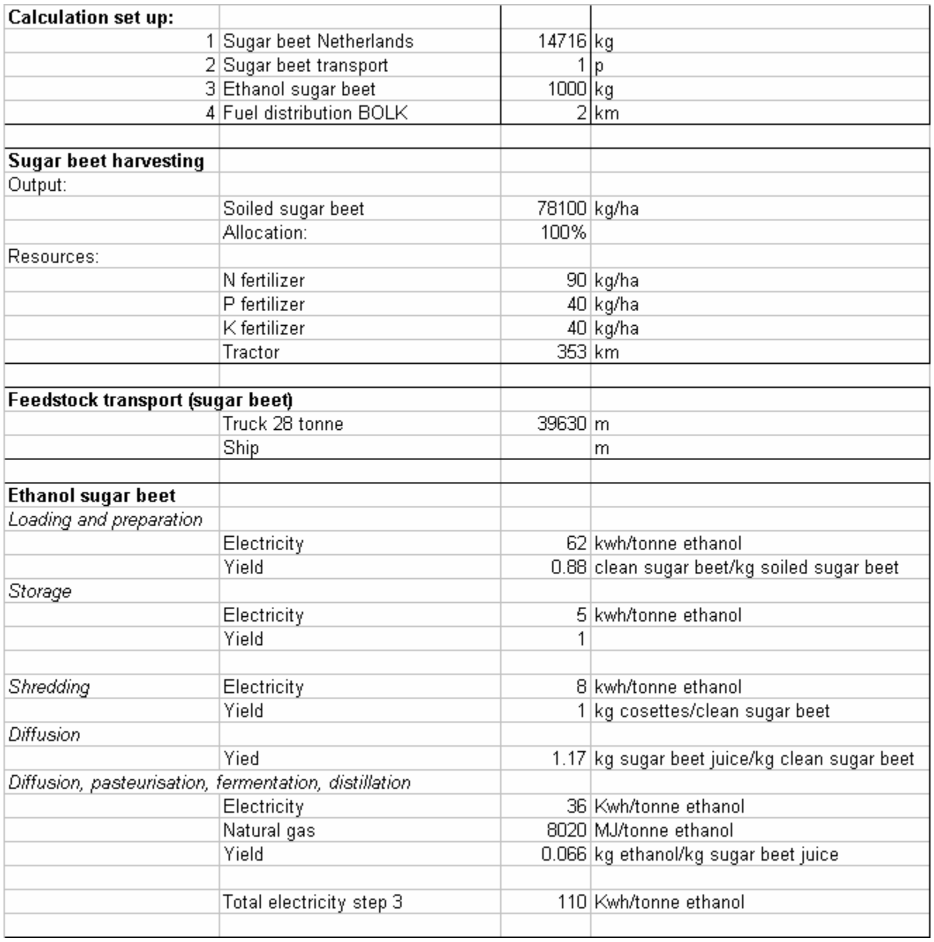
Calculation set up:			
1	FFB harvested	4763	kg
2	Biodiesel feedstock (oil +seeds) trans	1	p
3	Biodiesel palm oil	1000	kg
4	Fuel distribution BOLK	1786	m
Fresh Fruit Bunches harvested			
Output:			
	FFB	23300	kg/ha
	Allocation FFB	100	%
Resources	N fertilizer	114	kg/ha
	P fertilizer	19	kg/ha
	K fertilizer	177	kg/ha
	Tractor I	305	km
	Dirty truck (Truck I)	117	tkm
Biodiesel feedstock (oil +seeds) transport BOLK			
	Palm oil transport 28t truck	3445	m
	Palm oil transport sea ship	6	m
Biodiesel palm oil BOLK			
Output			
	Biodiesel Palm oil	1000	kg
	Glycerine	100	kg
	Allocaltion RME	87	%
	Allocation Glycerine	13	%
Extraction	Natural gas	1409	MJ/tonne FFB
	Electricity	15	kwh/tonne FFB
	Yield palm kernel	35	kg/tonne FFB
	Yield	221	kg CPO/tonne FFB
	Allocaltion CPO	61	%
	Allocation palm kernel	39	%
--			
Refining	Natural gas	0	MJ/tonne RPO
	Electricity	0	kwh/tonne RPO
	Phosphoric acid	0	kg/tonne RPO
	Yield	1	kg RFO/kg CPO
Esterification	Natural gas	1509	MJ/tonne palmdiesel
	Electricity	29	kwh/tonne palmdiesel
	Methanol	108	kg/tonne palmdiesel
	Yield	0.95	kg palmdiesel/kg RPO

Ethanol from sugar cane



Calculation set up:					
1	Sugar cane harvesting	13699	kg		
2	Sugar cane transport	1	p		
3	Ethanol from beet	1000	kg		
4	Fuel distribution BOLK	1	p		
Sugar cane harvested					
Output:					
	Sugar cane	75000	kg/ha		
	Allocation	100	%		
Resources					
	N fertilizer	60	kg/ha		
	P fertilizer	8	kg/ha		
	K fertilizer	13	kg/ha		
	Tractor	308	km	2617	MJ/ha/yr
				43	MJ/kg
				0.2	kg/km
Feedstock transport (sugar cane)					
	Truck 28 tonne	37	km		
	Ship		km		
Ethanol sugar cane					
Milling and ethanol production: complete process		*Heat is generated by bagasse-> calculation below*			
	H2SO4	11	kg/tonne ethanol from sugar cane		
	NaOH	14	kg/tonne ethanol from sugar cane		
	Cyclohexane	0.76	kg/tonne ethanol from sugar cane		
	Yield	0.073	kg ethanol/kg sugar cane		
	Excess bagasse	42	kg bagass/kg ethanol		
Bagasse combustion:					
Per tonne cane					
Production	280	kgbagass/tonne cane			
Excess (15%)	42	kgbagass/tonne cane			
Thus used	238	kgbagass/tonne cane			
Per tonne ethanol:					
Production	20	kg bagasse/tonne ethanol			
Excess (15%)	3	kg bagasse/tonne ethanol			
Thus used	17	kg bagasse/tonne ethanol			
Emissions			*Total emissions per tonne of ethanol*		
PM	7	g/kg bagasse		123	g/kg bagasse
PM-10	0.62	g/kg bagasse		11	g/kg bagasse
CO2	0.71	g/kg bagasse		12	g/kg bagasse
Nox	0.54	g/kg bagasse		9	g/kg bagasse
Polycyclic organic matter	0.0005	g/kg bagasse		0.01	g/kg bagasse
Fuel Distribution BOLK					
	Truck 28 tonne	1786	m		
	Ship	6	m		

Bioethanol from sugar beet

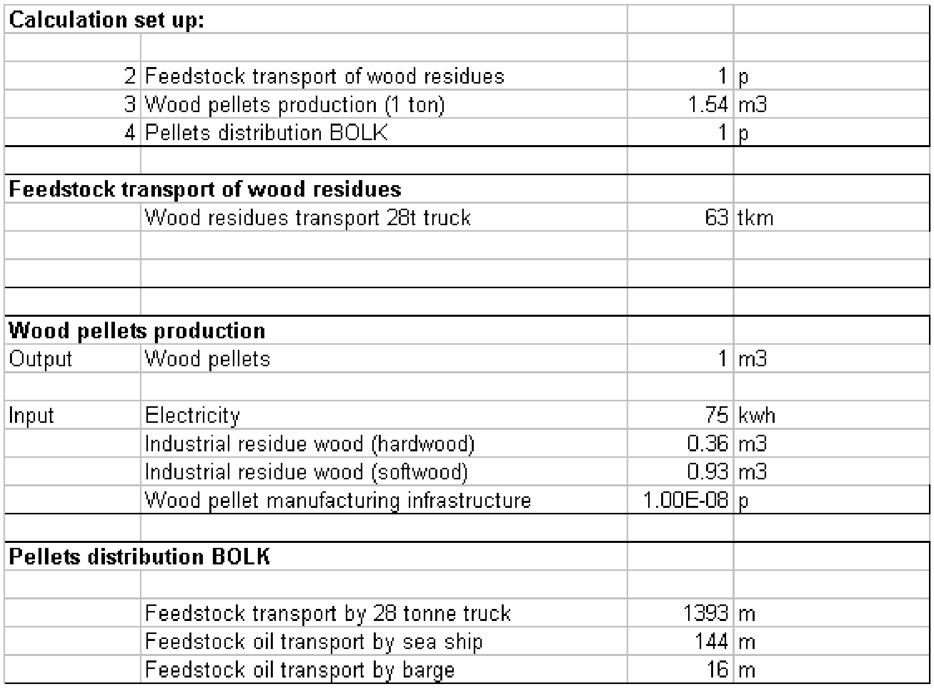


Calculation set up:			
1	Sugar beet Netherlands	14716	kg
2	Sugar beet transport	1	p
3	Ethanol sugar beet	1000	kg
4	Fuel distribution BOLK	2	km
Sugar beet harvesting			
Output:			
	Soiled sugar beet	78100	kg/ha
	Allocation:	100%	
Resources:			
	N fertilizer	90	kg/ha
	P fertilizer	40	kg/ha
	K fertilizer	40	kg/ha
	Tractor	353	km
Feedstock transport (sugar beet)			
	Truck 28 tonne	39630	m
	Ship		m
Ethanol sugar beet			
Loading and preparation			
	Electricity	62	kwh/tonne ethanol
	Yield	0.88	clean sugar beet/kg soiled sugar beet
Storage			
	Electricity	5	kwh/tonne ethanol
	Yield	1	
Shredding	Electricity	8	kwh/tonne ethanol
	Yield	1	kg cosettes/clean sugar beet
Diffusion			
	Yied	1.17	kg sugar beet juice/kg clean sugar beet
Diffusion, pasteurisation, fermentation, distillation			
	Electricity	36	Kwh/tonne ethanol
	Natural gas	8020	MJ/tonne ethanol
	Yield	0.066	kg ethanol/kg sugar beet juice
	Total electricity step 3	110	Kwh/tonne ethanol

CPO for heat/Electricity

Calculation set up:			
1	FFB harvested	4525	kg
2	Biodiesel feedstock (oil +seeds) trans	1	p
3	Biodiesel palm oil	1000	kg
4	Fuel distribution BOLK	1786	m
Fresh Fruit Bunches harvested			
Output:			
	FFB	23300	kg/ha
	Allocation FFB	100	%
Resources	N fertilizer	114	kg/ha
	P fertilizer	19	kg/ha
	K fertilizer	177	kg/ha
	Tractor I	305	km
	Dirty truck (Truck I)	117	tkm
Biodiesel feedstock (oil +seeds) transport BOLK			
	Palm oil transport 28t truck	3445	m
	Palm oil transport sea ship	6	m
Biodiesel palm oil BOLK			
Output	CPO	1000	kg
	palm kernel	158	kg
Extraction	Natural gas	1409	MJ/tonne FFB
	Electricity	15	kwh/tonne FFB
	Yield palm kernel	35	kg/tonne FFB
	Yield	221	kg CPO/tonne FFB
	Allocaltion CPO	61	%
	Allocation palm kernel	39	%
	Yield	4525	FFB/tonne CPO

Wood pellets for heat/electricity



Calculation set up:			
2	Feedstock transport of wood residues	1	p
3	Wood pellets production (1 ton)	1.54	m3
4	Pellets distribution BOLK	1	p
Feedstock transport of wood residues			
	Wood residues transport 28t truck	63	tkm
Wood pellets production			
Output	Wood pellets	1	m3
Input	Electricity	75	kwh
	Industrial residue wood (hardwood)	0.36	m3
	Industrial residue wood (softwood)	0.93	m3
	Wood pellet manufacturing infrastructure	1.00E-08	p
Pellets distribution BOLK			
	Feedstock transport by 28 tonne truck	1393	m
	Feedstock oil transport by sea ship	144	m
	Feedstock oil transport by barge	16	m

Annex B

Relevant emission factors for tractors as currently used by Simapro

Tractor input 1 km, with a diesel use of 0.28 kg diesel.

Emissions	**Amount**	**Unit**
Sulphur dioxide	0.0003	Kg
Nitrogen oxides	0.012	Kg
NMVOC	0.00001	Kg
Pentane	0.0001	Kg